

Energy Conservation in Multi-family Housing
in a Hot and Humid Climate

by

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ABSTRACT: ENERGY CONSERVATION IN MULTI-FAMILY HOUSING
IN A HOT AND HUMID CLIMATE

SIMON ROGERS WILTZ

Submitted to the Department of Architecture
on January 21, 1976
in partial fulfillment of the requirements
for the degree of Master of Architecture

The central task of the designer/architect/builder sympathetic to energy and environmental conservation is the development of a working knowledge of the macro and micro climate conditions under which his/her project will exist.

This thesis is both a design of multi-family housing in response to natural energies in a hot and humid macroclimate, and a proposal which combines natural energies with conventional mechanical apparatus and energies. The project uses the simple principles of "sources" and "sinks" for heating and cooling; the sun as a "source" of heat in the heating season, the wind as such for cooling when humidity is low and air temperature is somewhat high, and water from a lake at the site as a sink for hot air and a source of coolness to saturate water laden air at periods of high humidities.

Thesis Supervisor: Timothy Johnson
Title: Research Associate and Lecturer

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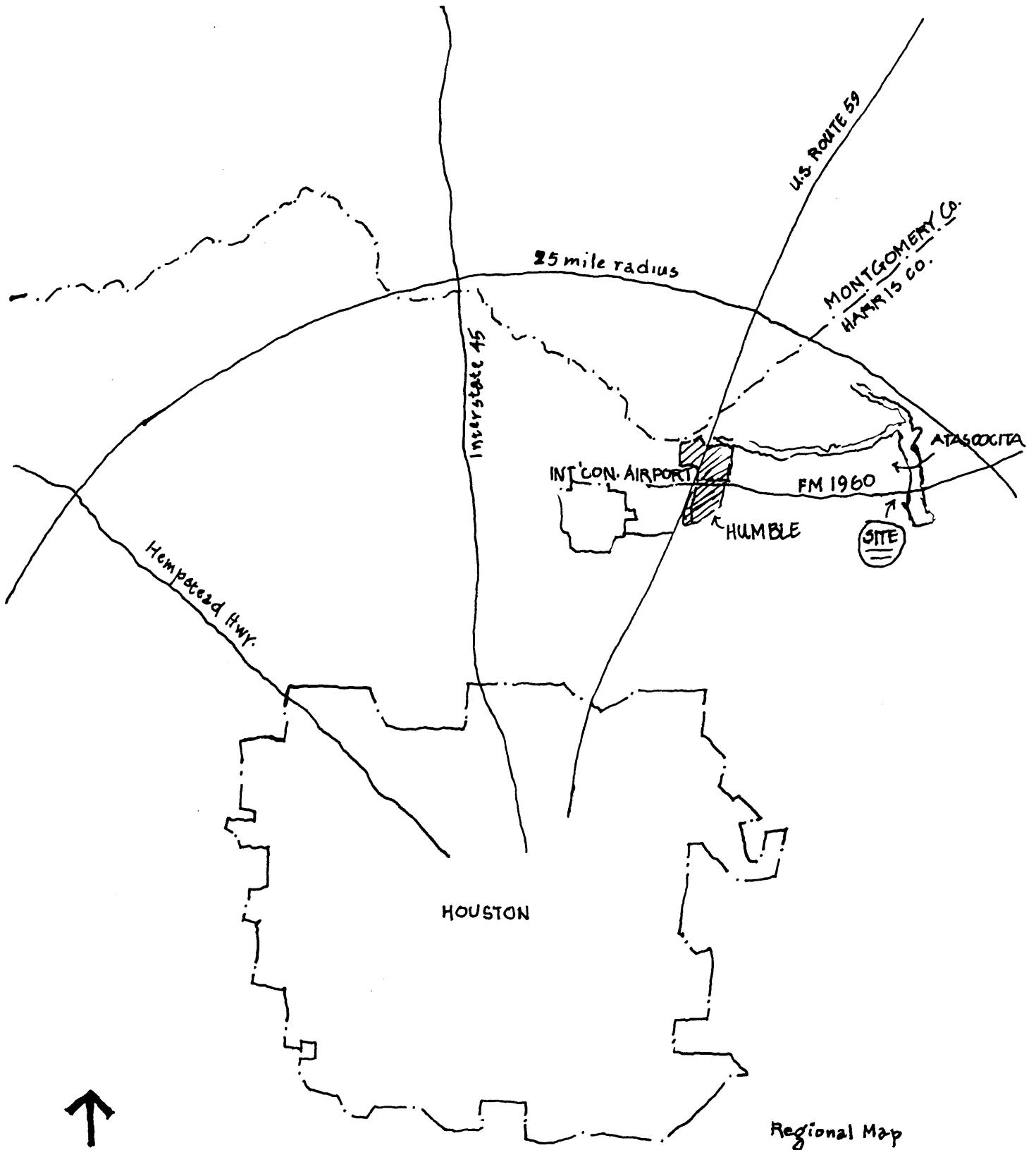
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This thesis is dedicated:

To Glenn, first and foremost, for her love and support
and, secondly, to the late Honorable Elijah Muhammad
for the dicipline he instilled in me.

ACKNOWLEDGEMENT

I wish to thank my advisor and friend Tim Johnson for his constant help and support. Also, special thanks to Mike for being there, and to Abe also for being there, but especially for his fine hand, his ear (now incurably bent), and his heart of gold. Thanks also to Richard, Mom and Dad, Reynaldo, and Nacie, my typist who made a pile of mess look like a thesis paper.



1.0 Introduction

The awareness of our wasteful and heavyhanded (mis)use of energy resources is firmly established now under the media heading of "Energy Crisis." Perhaps the most important realization of the past two years is that we have overlooked alternative energy sources that are at once more abundant than present sources and also non-polluting. The sun, wind, water, and earth are sources of renewable, safe energy. Research is underway to explore the technical and financial feasibility of each of these sources.

But the essential problem facing us is changing our wasteful lifestyles in this country. This change can occur through helping people understand the amount of energy they consume and how to use it efficiently and conservatively. It can occur through the actions of designers, builders, and engineers; those who figure more prominently in the home building industry. Also, via the use of energy conserving building design, simple building methods, indigenous materials, low cost energy-efficient mechanical and electrical equipment.

1.1 Thesis Goals

- A. To develop an understanding of climate conditions in Houston, Texas.
- B. To investigate ways of dealing with site particulars such as sun and wind microclimate, access, building orientation, views, landscaping, and etc., to realize a more gainful use of the site by its occupants.

- C. To explore vigorous though less costly responses to the climate conditions when they are most severe using natural/existing site features or low technology systems or both.

1.2 The Regional Situation

The climatic region of primary concern in this project is the sub-tropical hot and humid climate. The site chosen within this region lies seventeen miles northeast of the central business district of Houston, Texas. This climate was chosen because it is the one with which the author is most familiar.

Houston is now "Boom Town, USA." It is growing by leaps and bounds taking in 1000 families per week. In a published report made in 1968, the Houston Galveston Area Council (HGAC) predicted that the population of Houston will reach 5,000,000 by 1990 and 9,000,000 by 2020. This same report projected that residential development will continue in the pattern of subdivisions along major highways and thoroughfares with single family detached houses. This was 1968. Since then, numerous multifamily housing developments have sprung up along those same roads representing a more reasonable approach to development in terms of density. These are usually two story buildings grouped together in rowhouse fashion oftentimes with one apartment atop the other and, rather infrequently, duplex apartments or town-houses. Seemingly, there is little observable energy conserving consciousness at play in the orientation of buildings

within many of these developments. This is regrettable because the benefits accrued by increased density are at least minimized or possibly negated by mindless siting and orientation. Such things have happened because energy had been cheap up until a couple of years ago. But then, Texans usually take oil for granted anyway.

1.3 Regional Context

The site itself represents a small chunk of a 5000 acre development called Atascocita Community. Atascocita is the very type of community projected by HGAC's 1968 report, single family detached houses. The project site is slated for more of the same. Atascocita Shores, the original name of the area, is itself that part of Humble, Texas which sits at the western shore of Lake (Sam) Houston. Lake Houston represents a widening of the San Jacinto River which (the river) comes up from Galveston Bay miles to the southeast. It then widens into an enormous lake and then closes back to approximately its original width to the northeast of Atascocita Community and then bends to the west to form a fork, one prong heads due west, the other to the north. The west fork forms the northern boundary of the Atascocita Community.

1.4 Regional Climatological Summary

Houston is located in the Hot Coastal Plains, about 50 miles from the Gulf of Mexico and about 25 miles from Galveston Bay. The climate is predominantly marine. Because the terrain includes numerous small streams and bayous, the

the development of ground and advective fogs are common. Meteorological data from the Department of Commerce show that the prevailing winds are from the south and south-southeast, except in January, when frequent passages of high pressure areas bring invasions of polar air and prevailing northerly winds.

Nearness to the Gulf and the influence of its winds moderate air temperatures. Results are mild winters and, on the whole, cool summer nights. Except for rare extended dry periods, rainfall is abundant and is somewhat evenly distributed over the year. Annual rainfall, measured at the Federal Building in downtown Houston, has varied from 72.86 inches in 1900 to 17.66 in 1917; 17.86 inches was recorded at Hobby Airport, located to the southeast of downtown, in 1946. Total precipitation over about 75% of the years measured are between 30 and 60 inches. Monthly precipitation measured at the downtown station has ranged from 17.69 inches to only a trace. Thunder showers are the main source of precipitation, subsequently it varies substantially in different parts of the city from day to day.

The average number of days with minimum temperatures of 32° or lower is only 7 per year at the downtown station, about 15° at the Hobby Airport, and about 23° at Intercontinental Airport located 10 miles due east of the site at the exact same latitude. Freezing temperatures generally last only a few hours since they are usually accompanied

by clear skies. However, in January - February 1951, the temperature remained 32° or below for 123 consecutive hours. The average date of the last temperature 32° or lower in spring is February 5, at the downtown station. December 11 is the average date of the first 32° temperature in fall. Table I shows that in 1974, 95 days were 90° and above (26% of the year).

Records indicate that one fourth of the days per year are clear, with a maximum of clear days in October and November. Cloudy days are frequent from December to May and partly cloudy days are more frequent from June through September. Sunshine averaged near 60% of the possible amount for the year at the downtown station for 1938-1960, ranging from 46% for the winter months to 69% for the summer. Data from the airports since 1961 indicate slightly higher percentages of sunshine. In 1974 at Intercontinental 51%, 26%, 67%, 43%, 56%, and 53% for December through May respectively.

Snow rarely occurs and in only one winter season, 1972-1973, when as much as three measurable snows were recorded. Heavy fog occurs on an average of 16 days per year, light fog about 62 days a year in downtown Houston. However, the frequency of heavy fog is higher at Hobby and Intercontinental.

Humidity emerges as the major comfort problem in this area. Table I shows that it rarely drops below 85% in the early morning and at night. These levels seriously affect

comfort requirements for restful sleep from June through most of September. During daylight hours coupled with the high dry-bulb temperature it is unbearable, even though it falls considerably by midday when air temperature is generally highest.

Summer daytime air temperatures are high, normally in the 90's from June through September with record highs in July and August of 101°F. Nighttime temperatures drop to about 70°, but nighttime comfort is foiled by high relative humidities generally 90 to 95 per cent.

Meteorological Data For The Current Year

Station: HOUSTON, TEXAS		INTERCONTINENTAL AIRPORT										Standard time used: CENTRAL		Latitude: 29 58 N		Longitude: 95 21 W		Elevation (ground): 96 feet		Year: 1974																																																			
Month	Temperature °F						Degree days Base 65 °F	Precipitation in inches						Relative humidity, pct.				Wind				Number of days Average sky cover, sunrise to sunset	Average station pressure mb																																																
	Averages			Extremes				Water equivalent			Snow, ice pellets			Hour				Resultant		Fastest mile			Sunrise to sunset		Precipitation		Snow, ice pellets		Thunderstorms		Heavy fog, visibility 1/4 mile or less		Temperature °F		Elev. feet m.s.l.																																				
	Daily maximum	Daily minimum	Monthly	Highest	Date	Lowest		Date	Heating	Cooling	Total	Greatest in 24 hrs.	Date	Total	Greatest in 24 hrs.	Date	Hour	Hour	Hour	Hour	Direction		Speed m.p.h.	Average speed m.p.h.	Speed m.p.h.	Direction	Date	Percent of possible sunshine	Clear	Partly cloudy	Cloudy	Precipitation 0.1 inch or more	Snow, ice pellets 1.0 inch or more	Thunderstorms		Heavy fog, visibility 1/4 mile or less	80° and above	32° and below	32° and below	0° and below																															
																																									Maximum		Minimum																												
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JAN	64.0	45.9	55.0	80	18	30	4	330	24	7.68	2.00	14-15	0.0	0.0		90	92	78	80	02	1.3	7.2	18	20	17	26	7.9	5	2	24	19	0	0	0	3	0	1015.2																																		
FEB	70.0	42.6	56.2	82	13	26	26	273	33	0.55	0.28	21	0.0	0.0		80	83	47	49	22	1.2	9.4	35	29	21	67	4.4	12	8	14	0	0	0	7	0	1015.2																																			
MAR	76.0	57.6	66.8	90	29	39	22	95	158	4.20	2.38	14-15	0.0	0.0		86	90	62	66	16	4.7	9.9	25	18	3	67	7.4	5	8	19	0	0	0	3	0	1011.9																																			
APR	77.9	56.5	67.2	88	1	39	6	60	132	1.68	0.82	11	0.0	0.0		87	87	50	61	13	4.7	9.1	23	16	21	56	5.8	10	9	13	5	0	4	0	0	0	1012.9																																		
MAY	86.1	67.7	76.9	93	31	55	7	0	374	5.61	2.71	9-10	0.0	0.0		88	91	62	67	13	4.6	7.5	20	17	30	53	6.4	4	1	12	10	0	4	10	0	0	1008.5																																		
JUN	91.0	68.8	79.9	98	23	57	27	0	454	0.59	0.22	9-10	0.0	0.0		82	86	50	53	14	3.3	7.3	32	13	5	74	4.3	12	19	5	5	0	0	23	0	0	1010.2																																		
JUL	94.2	71.3	82.8	98	28	67	18	0	538	1.75	0.95	1-2	0.0	0.0		85	90	52	54	19	3.3	6.7	40	12	2	70	5.3	10	18	8	10	0	10	0	0	0	1013.2																																		
AUG	90.9	72.2	81.6	96	1	70	6	0	519	6.94	3.21	1-2	0.0	0.0		90	91	64	70	12	3.3	6.1	29	20	29	53	6.9	4	13	14	16	0	17	0	28	0	0	1012.2																																	
SEP	82.9	66.2	74.6	95	2	32	30	0	295	4.51	2.13	14	0.0	0.0		89	91	68	74	04	3.2	6.6	31	30	8	47	6.3	8	6	16	9	0	6	6	0	0	0	1011.5																																	
OCT	82.4	58.8	70.6	89	6	42	16	15	196	4.53	2.05	31	0.0	0.0		95	96	61	77	09	4.1	7.6	29	13	28	64	4.7	12	10	9	9	0	2	4	0	0	1	0	1017.6																																
NOV	70.7	49.7	60.2	85	3	31	30	196	60	7.90	3.59	31-1	0.0	0.0		87	89	62	73	05	3.0	6.4	24	34	30	47	6.1	10	4	16	11	0	4	9	0	0	7	0	1016.3																																
DEC	65.9	43.2	54.6	83	30	29	1	336	18	3.25	0.95	10	0.0	0.0		85	89	62	78	02	0.7	6.4	23	30	24	51	6.3	8	8	15	12	0	1	9	0	0	0	7	0	1015.6																															
YEAR	79.3	58.4	68.9	98	JUL 28	FEB 26		1905	2821	49.29	3.55	31-1	0.0	0.0		87	90	60	67	12	2.1	6.1	40	12	JUL 2	55	6.0	100	107	158	114	0	71	40	86	0	18	0	1013.4																																

Normals, Means, And Extremes

Month	Temperatures °F							Normal Degree days Base 65 °F	Precipitation in inches										Relative humidity pct.				Wind				Pct. of possible sunshine	Mean sky cover, tenths, sunrise to sunset	Mean number of days										Average station pressure mb.																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																		
	Normal			Extremes					Water equivalent					Snow, ice pellets					Hour 00	Hour 06	Hour 12	Hour 18	Mean speed m.p.h.	Prevailing direction	Fastest mile				Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, ice pellets 1.0 inch or more	Thunderstorms	Heavy fog visibility % mile or less	Temperatures °F		Elev. feet m.s.l.																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																			
	Daily maximum	Daily minimum	Monthly	Record highest	Year	Record lowest	Year		Heating	Cooling	Normal	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Maximum monthly							Year	Maximum in 24 hrs.										Year	Speed m.p.h.		Direction	Year	Sunrise to sunset	90° and above	32° and below	32° and below	0° and below																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																												

Extremes for period June 1969 to date.
Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows:
Highest temperature 108 in August 1909; lowest temperature 5 in January 1940 and earlier; maximum monthly precipitation 22.31 in October 1949;
minimum monthly precipitation Trace in October 1952 and May 1937; maximum precipitation in 24 hours 15.65 in August 1945; maximum monthly snowfall 4.4 in February 1960; maximum snowfall in 24 hours 4.4 in February 1960; fastest mile of wind 84 from NW in March 1926.

- (a) Length of record, years, through the current year unless otherwise noted, based on January data.
(b) 70° and above at Alaskan stations.
* Less than one half.
T Trace.

NORMALS - Based on record for the 1941-1970 period.
DATE OF AN EXTREME - The most recent in cases of multiple occurrence.
PREVAILING WIND DIRECTION - Record through 1963.
WIND DIRECTION - Numerals indicate tens of degrees clockwise from true north. 00 indicates calm.
FASTEST MILE WIND - Speed is fastest observed 1-minute value when the direction is in tens of degrees.

2.0 Site Design Goals

2.1 Site Context

The location of the site with respect to major public transportation linkages make it necessary for its users to depend almost entirely on cars. Regional shopping centers are 5 miles away on FM 1960 and U.S. Rt. 59. Houston, the major employment center is 17 miles south via U.S. 59.

There is a convenience market across the lake on the east bank of the lake on FM 1960 accessible by bridge or boat. Public transportation to Houston is provided by bussing via the "Rapid Transit" system of Greater Houston which has stops in the central business district of Humble.

2.2 Density

People and units per acre will be increased, from the norm of 12 people/acre at 4 units/acre to 21 people/acre at 8 units/acre. The feeling here is that increasing density is an important axiom of energy conservation. The mixed land use concept at a small scale is at work here. Smaller parcels of individually owned land are in use thus allowing more area for common outdoor activities.

2.3 General Plan Objectives

The site design is a response to both natural and mechanical forms of energy (detailed discussion to follow) and a reaction to the existing and proposed plans for the Atascocita Community. Also, a reaction to elements of the Reston, Virginia Community Plan, a section that I saw some time ago for multi-family lake-front housing. The Reston

Reston's section

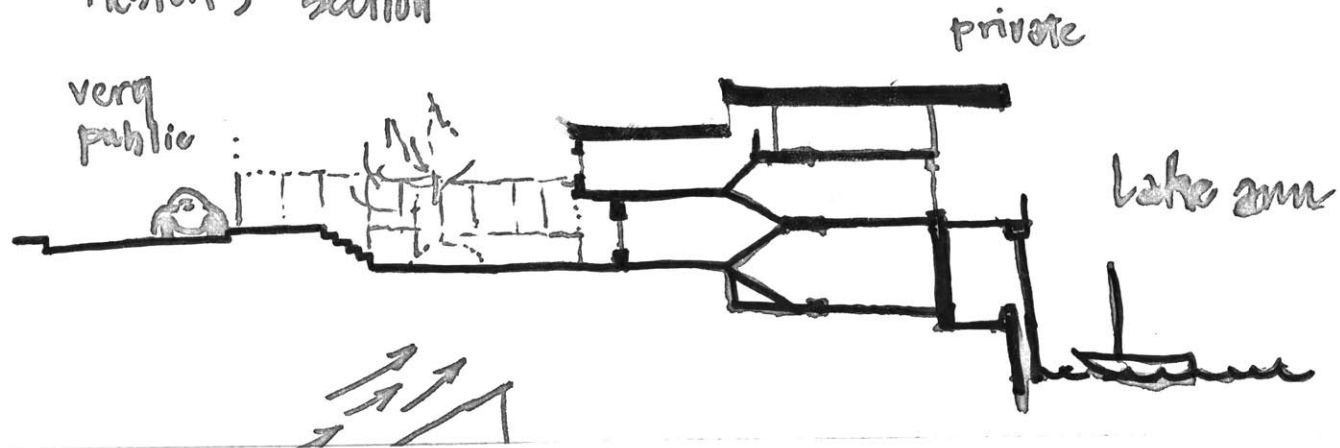
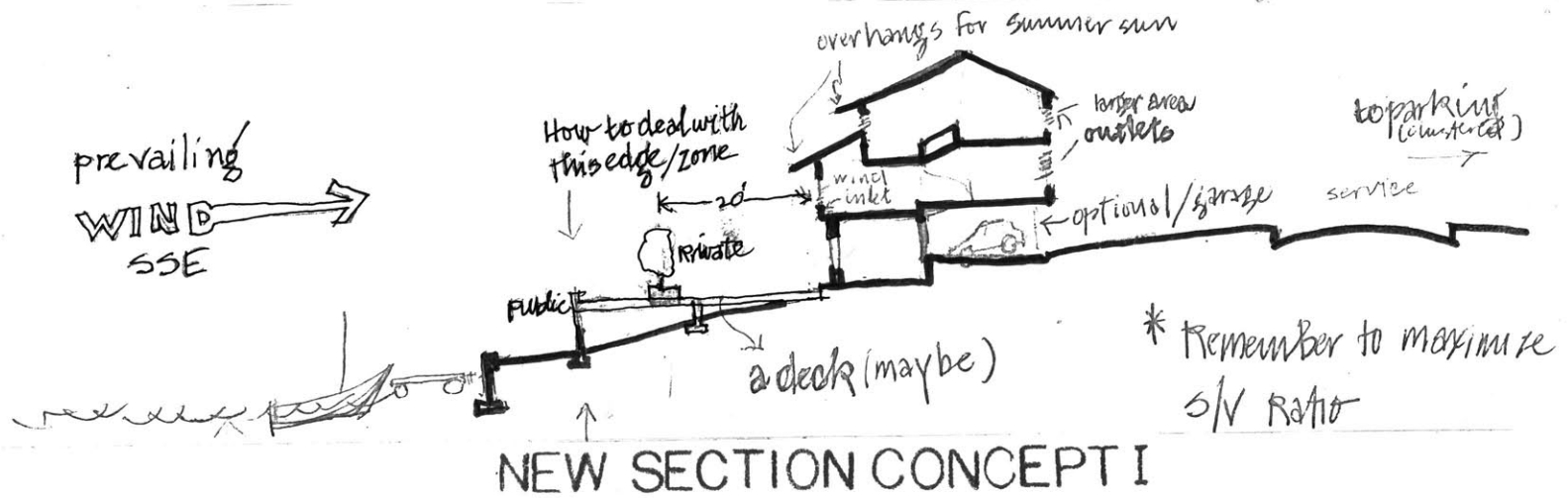
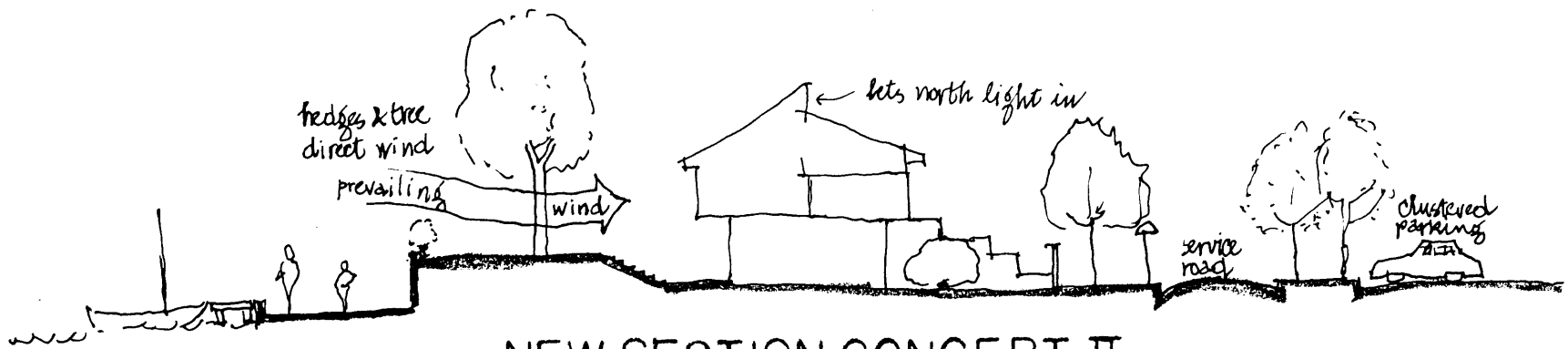


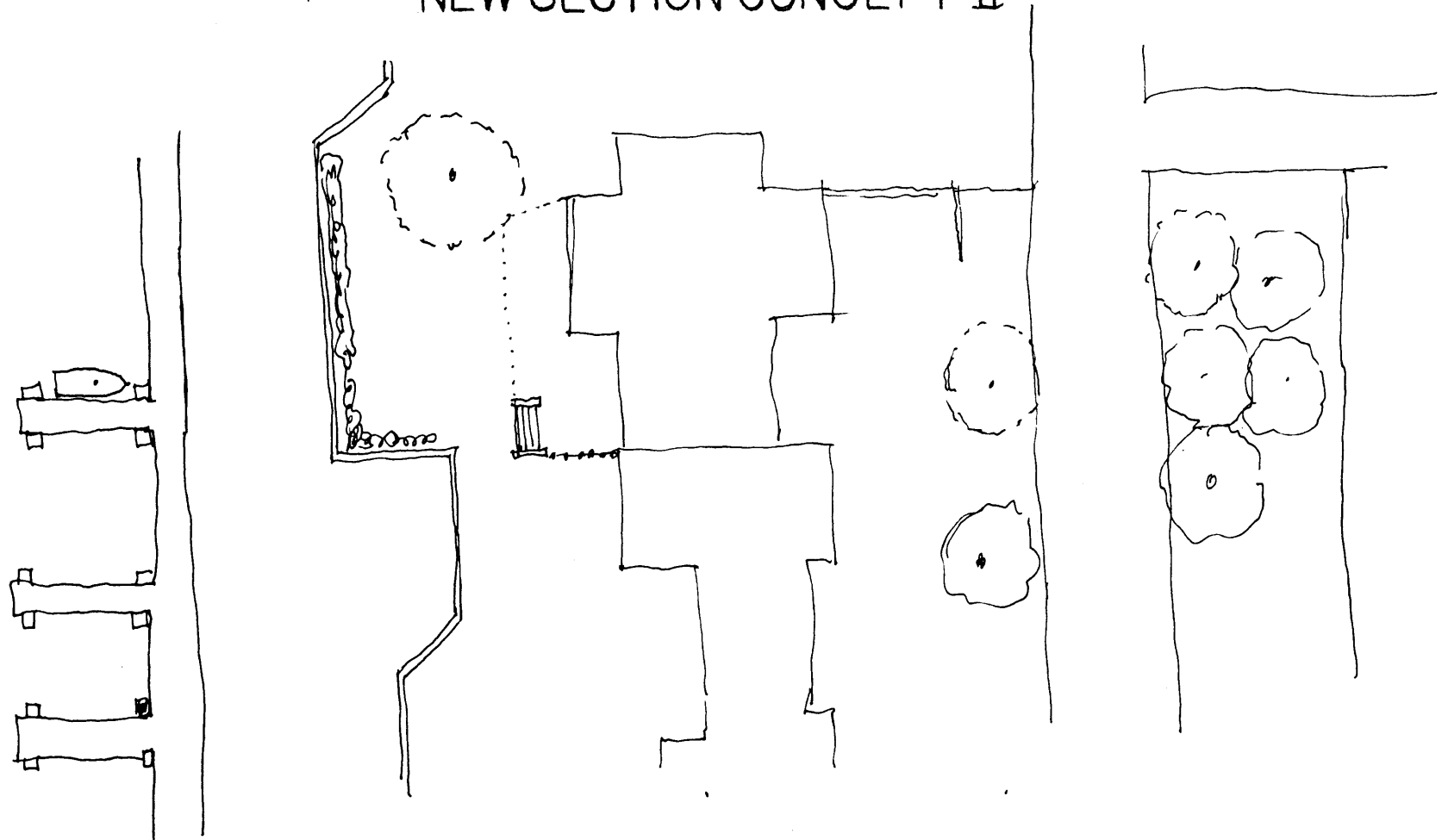
Diagram 4





NEW SECTION CONCEPT II

Diagram II



and Atascocita attitudes are that the houses should back or front right on the lake's edge not allowing public access along the edge making it very private. Not an unattractive amenity I must say, but my feeling is that the lake's edge offers an opportunity for a different kind of life/activity that will enhance the site itself and connect it with the adjacent property to the east and recreation center to the west in a way more amenable than existing sidewalks and roads.

2.31 Cluster Plan

The site plans shows that the houses are clustered in a rowhouse fashion. The advantages of doing this is both energy and cost conservation. Construction work is localized, utility lines are shortened (cutting distribution costs), and shared walls cut down heat loss and materials cost. A 'large' house, 20 feet by 32 feet and a 'small' house 20 feet by 24 feet is used to handle varying family groupings. Future growth is facilitated by placing circulation spaces in each house along approximately the same line. Combination/connection is made through the wall via a fire-rated door placed there during construction. Steps up or down can be added when growth is implemented.

Growth is limited to one large and one small house to the West and to two small houses to the East or West. This is controlled by the way the houses are set back thus affecting the registration of circulation spaces.

2.4 Program Specifics

A. Private Zones

1. Large House: nuclear or extended families with provisions for:

Activities

cooking

eating

sleeping

working

lounging

storing

2. Small House: couples or old newly weds,
young elderly
or small families with same provisions as listed above though smaller.
3. Combination: communes or therapeutic groups.
Large + Small = Larger

B. Public Zones

1. Commercial/Communal Facility
 - a. "Mom and Pop" variety/drug store
 - b. Meeting room with super screen television
 - c. Snack bar
 - d. Restrooms
 - (1) dressing
 - (2) lockers
 - (3) showers
2. Recreation
 - a. Swimming

- (1) beach
 - (2) wading pool
 - b. Boating
 - (1) boat piers
 - c. Active play areas
 - (1) tot lot
 - (2) open play area
 - d. Meditation
 - (1) garden
- 3. Parking
 - a. $1\frac{1}{2}$ car/unit
 - b. $\frac{1}{4}$ car/unit (visitor)

3.0 Building Design and Natural Energy Usage

3.1 Why Use Natural Energies?

The use of natural energies to heat or cool housing offer us the general advantages of free, clean, and therefore healthier comfort conditioning from the adjacent natural environment. This thesis is advocating the design of buildings in which comfort conditions are provided non-mechanically from natural forces, to the limit of their effectiveness in providing comfort, and supplementing that with minor mechanical assists.

A report by Richard G. Stein and Associates, "Research and Recommendations for a Low Energy Utilization School for New York City," lists several factors supporting the attitude taken by this thesis. The following is an abstraction of that list.

- "1. Statistics indicate that buildings which rely entirely on mechanical and electrical systems for environmental control use considerably more fuel in their operation than do those which use natural means supplemented with back-up systems.
2. buildings which rely entirely on mechanical and electrical systems for environmental control perform no better and in some cases, less well in providing prespecified environmental conditions.
3. Increases in complexity of systems varies directly with potential malfunctions at a rate determined not only by the number of components, but also by

increased relationship between components.

4. Electronically controlled systems with pre-selected conditions fail to respond to actual human needs unless local, manual input is provided.
5. Buildings which use natural energies with mechanical supplements are less susceptible to the pressures of rationing and high fuel costs.
6. The changes and unpredictability of naturally delivered energies provide relief from environmental boredom and sensitizes people to their immediate microclimate.
7. The need to involve people in the control of their environment speaks to the need to modify mechanical systems' operation. Similarly, the ability to vary conditions by non-mechanical means such as opening windows or drawing shades and blinds involve people in the act of conserving energy."

3.2 Positive and Negative Energy Flow

The following convention was developed in the "Stein Report" to quantify and evaluate mechanical and non-mechanical systems in terms of their impact on fuel consumption:

- A. "Positive Energy Flow: Any non-mechanical transmission of energy through a building skin which would otherwise have to be mechanically transmitted will be positive, the value being equal to the source energy required by mechanical process.
- B. Negative Energy flow: Any transmission of energy

through the skin of a building which results in the need to operate a mechanical system to counter the effect of the transmission will be negative, the value being equal to the source energy required by the mechanical process. In terms of conserving fuel, positive energy flow will always be desirable, negative always undesirable."¹

The effectiveness of my building skin is then determined by net diurnal positive flow in winter and summer by mechanical and non-mechanical means.

3.3 Planning Considerations at Site and Unit Scales for Sun and Wind Penetration

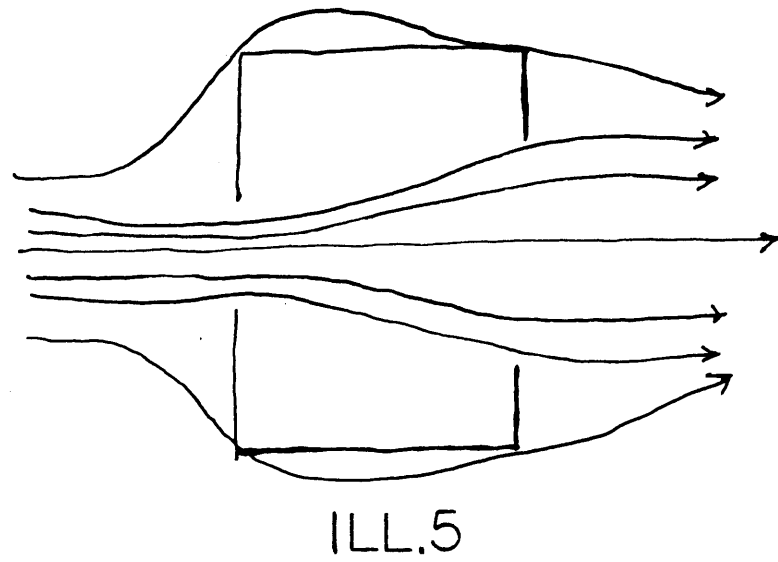
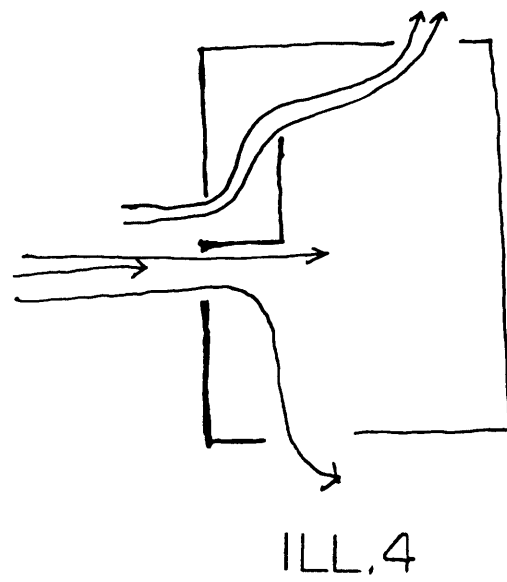
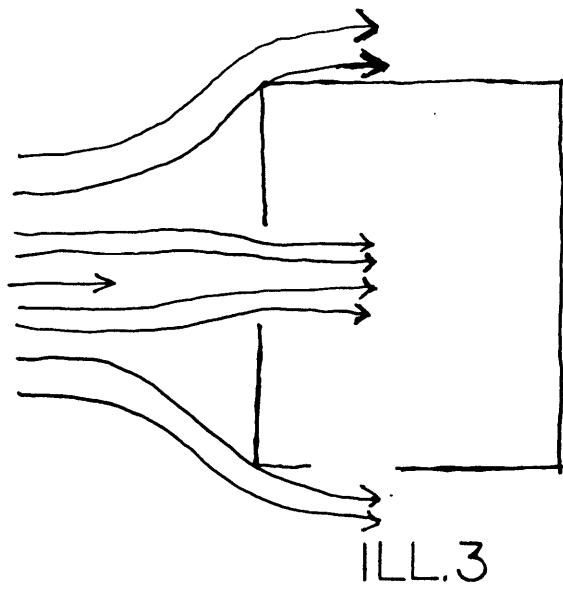
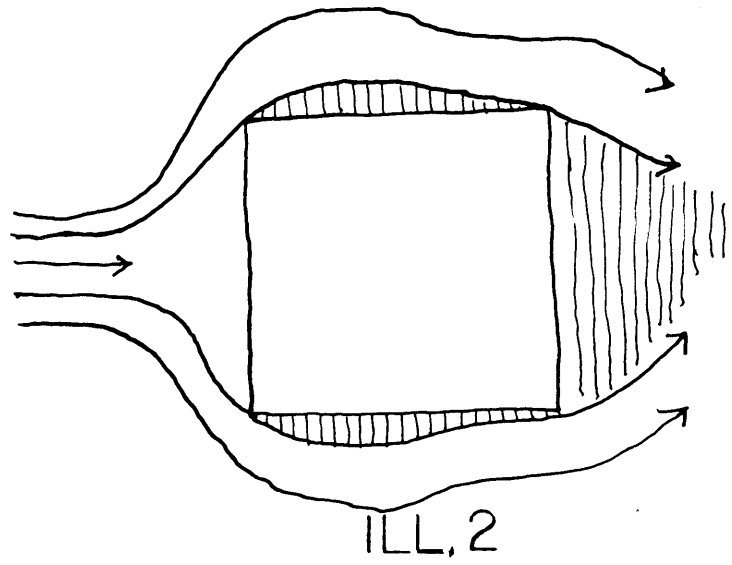
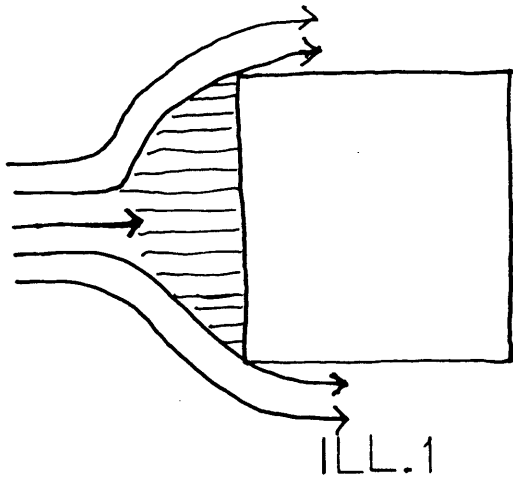
At the site scale, massing, orientation, other buildings, topography, and planting are taken into consideration. Each of these affect sun and wind penetration. At this site we are fortunate that the prevailing wind comes from the general direction of the sun. This means that windows on the south wall can serve to admit heat, light, or wind (when open). Shading devices (overhangs, fence/walls) are designed to block the penetration of solar radiation from late spring to early fall (solar altitude 65° to 83.5°). (See Calculation I)

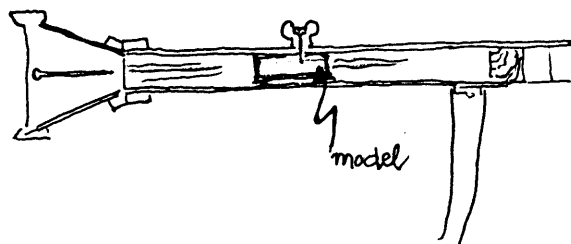
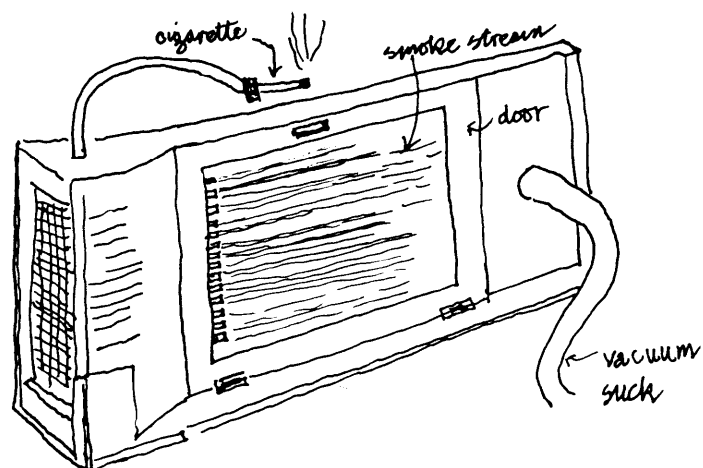
Site and unit planning for natural cooling/ventilation requires a familiarity with the primary characteristics of

¹R.G.Stein and Associates, "Research and Recommendations for a Low Energy Utilization School for New York City"

air flow. When air moves to a building(s) it will pile up and slow down and move along and around the building(s) until it finds a new path. The affected area is a high pressure area (ill. 1). The inlet should be placed in this area as the pressure will force the air through the opening. On the opposite side of the building and to a lesser extent on the sides the pulling force of the air passing around the building cause low pressure areas called wind shadows. Outlet openings should be located in these low pressure areas as the pulling/negative pressure will pull the air out of the building (ill. 2).

In designing interior walls/screens the principle of inertia must be understood (ill. 3). The air will enter an opening continuing in the same direction until an obstacle (wall) is placed in its path changing its direction or another opening is placed in its path changing its direction or another opening is placed on a low pressure side causing the natural flow from high to low pressure (ill. 4). (In this design floor to ceiling walls on the windward side (high pressure) are avoided because they tend to slow and redirect the flow air. As open a plan as possible is necessary.) Using large openings allows maximum air changes and unequal openings with the larger on the leeward (low pressure) side increases air speeds (ill. 5). Flow patterns through the space are determined by the location of openings. Although flow patterns can be predicted to some degree given the foregoing information other factors

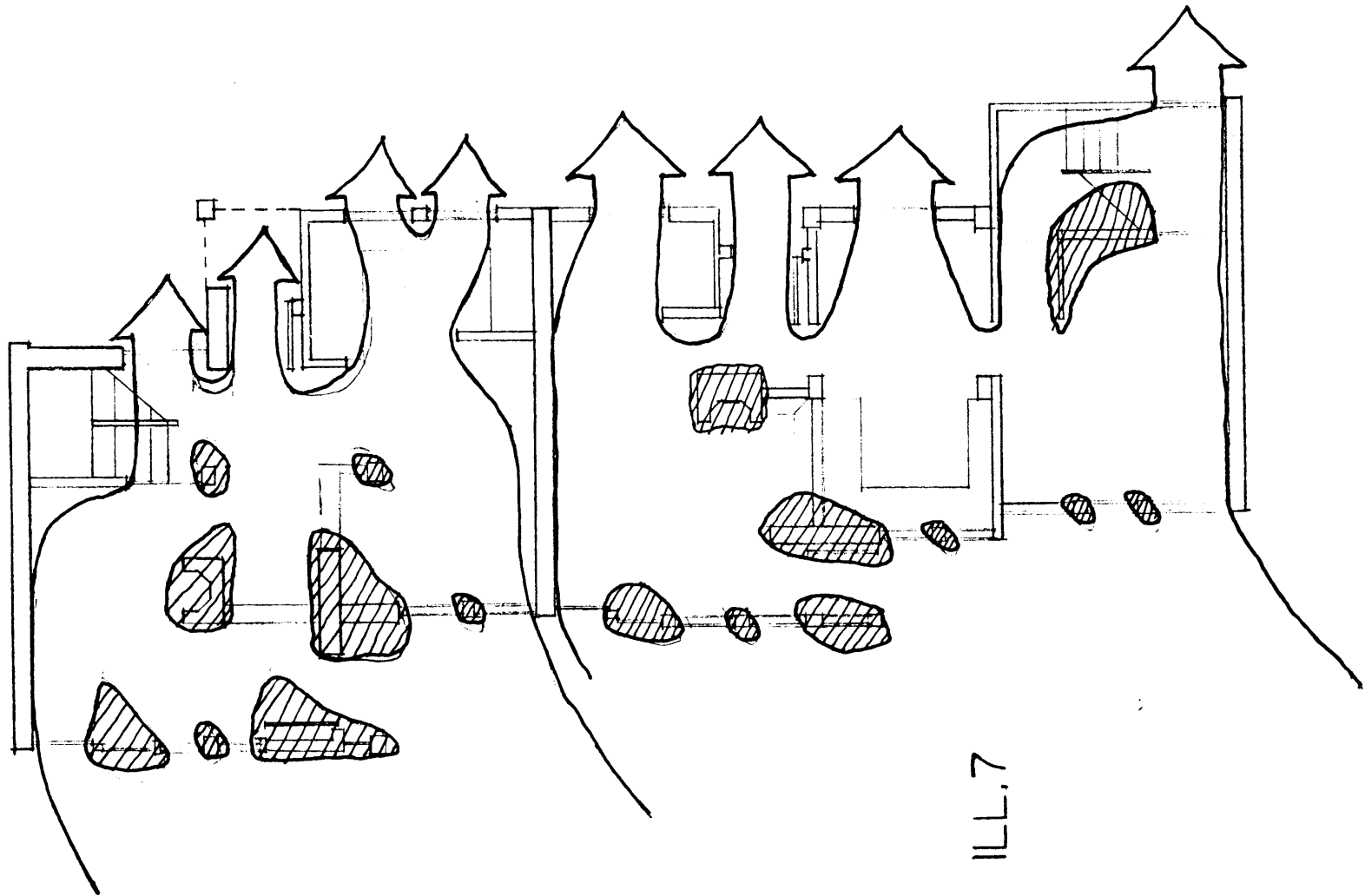




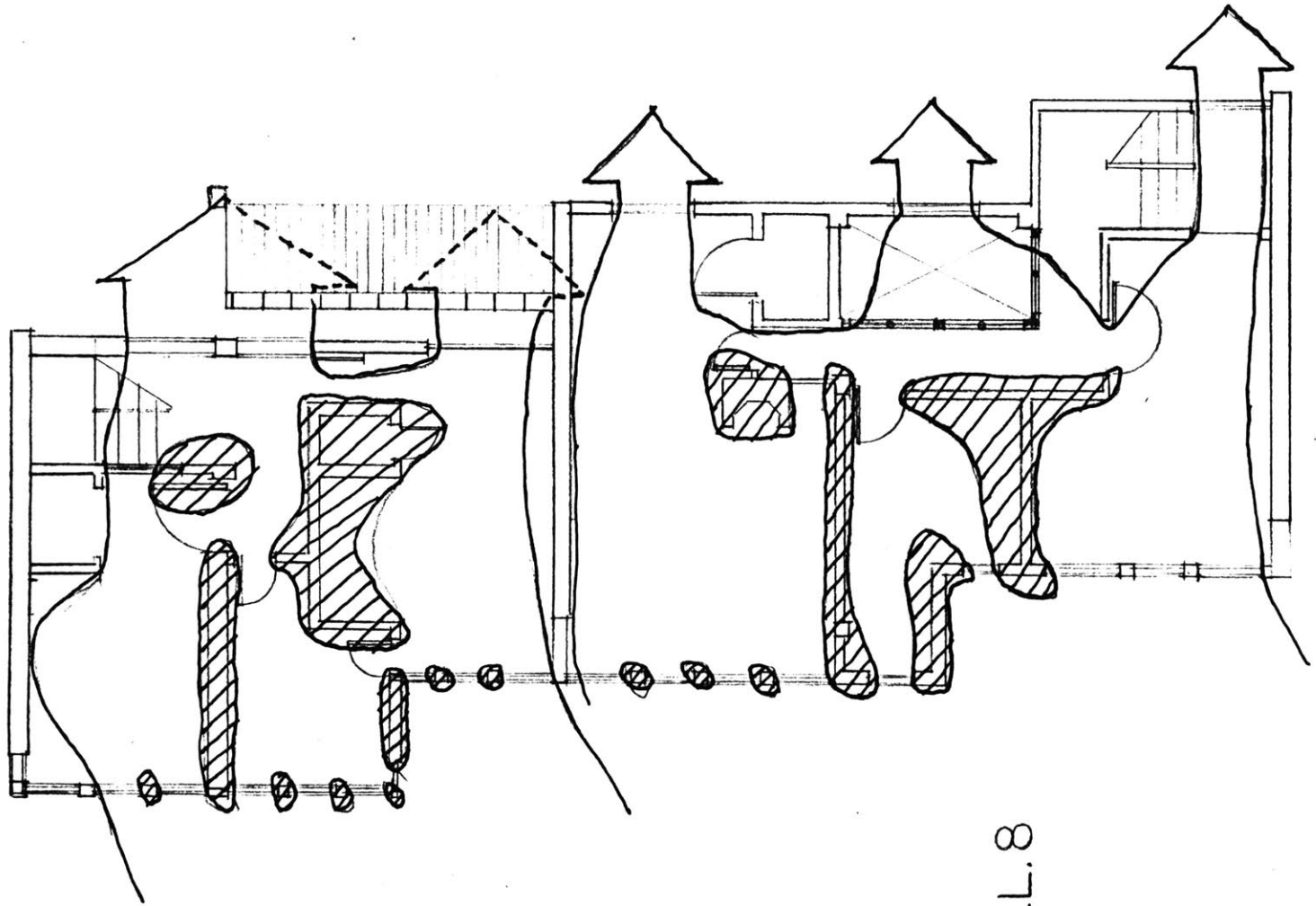
suction-type smoke tunnel from The Scientific American Book of Projects for the Amateur Scientist - 1960

TEST APPARATUS

ILL. 6

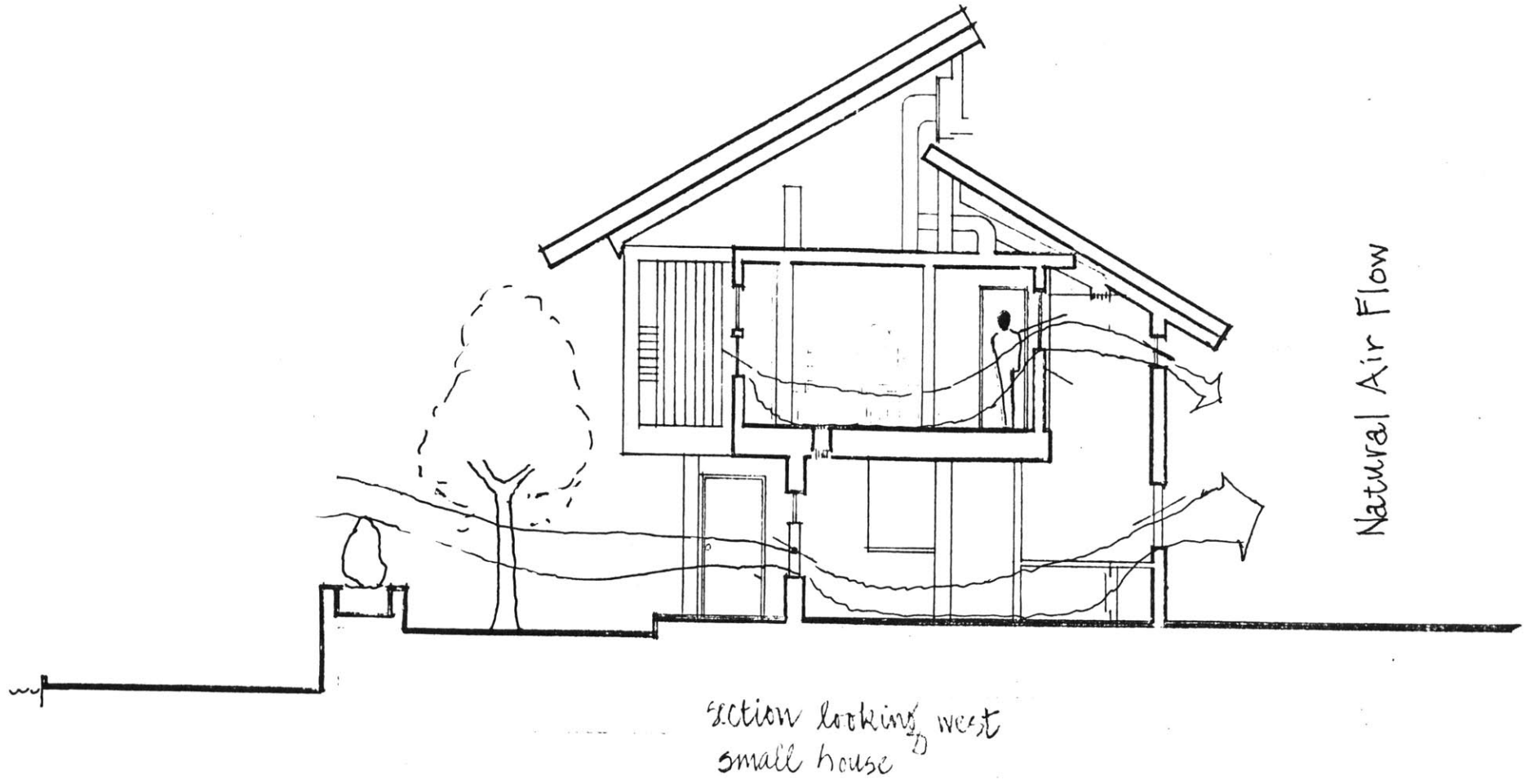


NATURAL AIR FLOW
level one

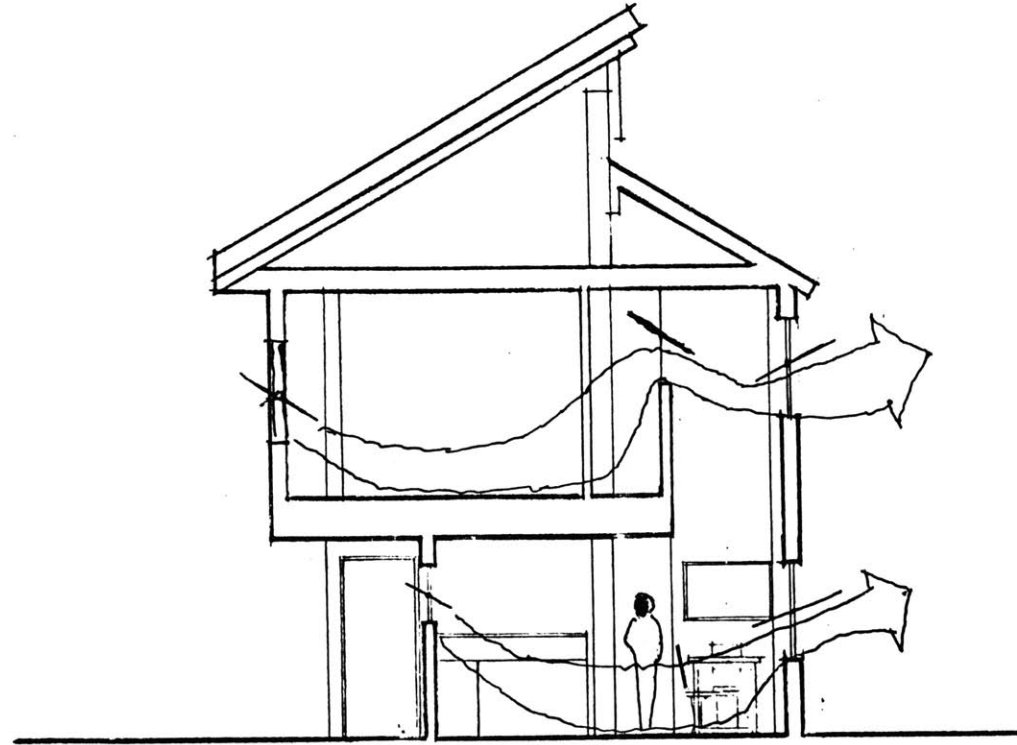


ILL. 8

NATURAL AIR FLOW
level Two



NATURAL AIR FLOW



section looking west
large house

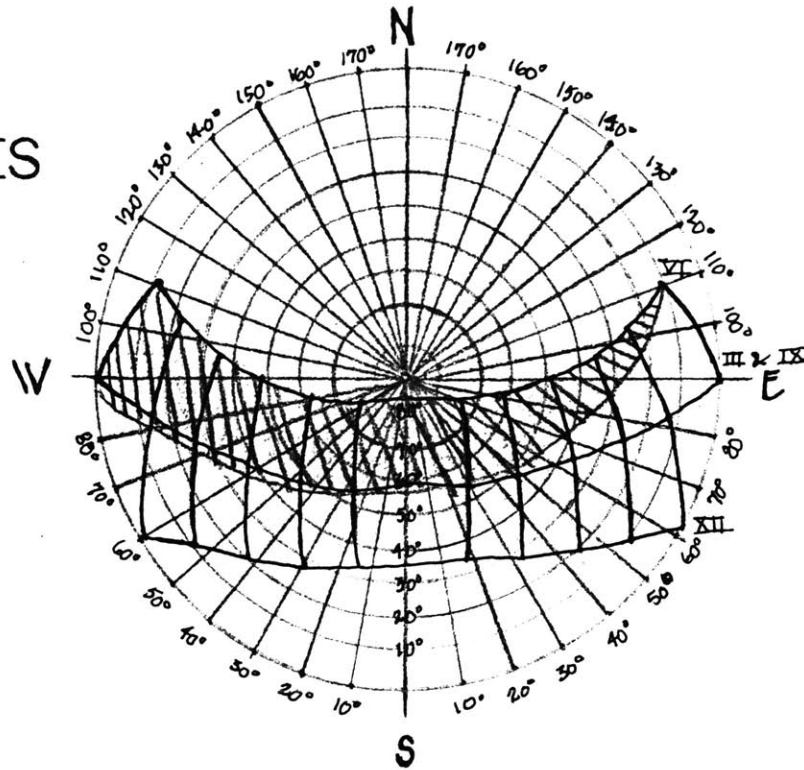
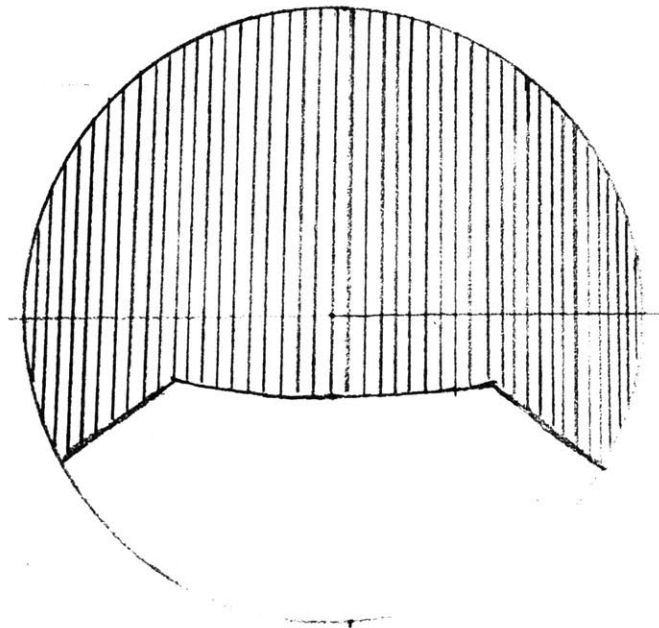
must be taken into account such as topography, planting, overhangs, and other buildings. Modelling and testing incorporating all elements must be done for better understanding of the effects of external and internal factors.

3.31 Building Skin Performance in Winter and Summer

The effectiveness of a building skin is determined from its ability to maximize positive energy flow and minimize negative energy flow to the space it covers.

The transmission of U-Factors in this project are set at 0.05 for opaque walls. 0.55 for windows (double glazing is used here both for its transmission of 0.81 for reasonable heat gain in winter, and for its low U-Factor 0.55 as opposed to single glazing which is 1.15. This cuts negative flow in half in summer and winter), and 0.08 for roofs. There is 50% glazing on the southward faces and 30% glazing on the northward faces. See Table II and III.

Diagram III

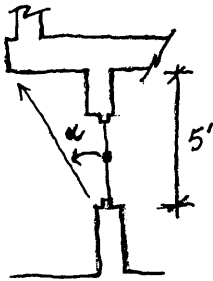
SUN
ANGLESSHADING
DIAGRAM

CALCULATION I

Shading Design Calculations

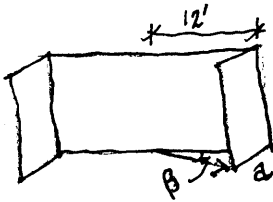
$$5' \tan 25^{\circ} = 2\frac{1}{2}'$$

$$(5) (0.466) = 2\frac{1}{2}'$$



for 100% shading at
solar altitudes of 65°
to 83.5 (maximum at 30° N
Latitude)

Vertical Shading



$$12 \tan 35 = a$$

$$(12) (0.70) = 8.4$$

TABLE II

HEAT LOSS (winter)

Item	Volume area or length	U-Factor or other unit	Delta T°F	Heat Loss	BTU hr
Wall	1128	X 0.05	X 28°	1,579	BTU hr
Glass (double)	390	X 0.55	X 28°	6,006	BTU hr
Door (X2)	21	X 0.48	X 28°	282	BTU hr
Roof	820	X 0.08	X 28°	1,837	BTU hr
Infiltration	4000 cuft/hr	X 0.0182	X 28°	2,038	BTU hr
Slab edge	68 linear ft	X 32 BTU/ft		2,176	BTU hr
				<hr/> 13,918	

HEAT GAIN (winter) January 21, 9:00 a.m.

	BTU/hr/SF	SF	Trans- mission	%Cloudy	Gain
South facing window	109	240	0.81	0.50	10,595
Southeast facing window	161	240	0.81	0.50	15,649
*Southwest facing window	9	240	0.81	0.50	875

*Windows can be made to face south to get net positive flow.

HEAT LOAD (Summer)

Table III

<u>Item</u>	<u>Area, volume or length</u>	<u>U-Factor or other unit</u>	<u>Delta T^oF</u>	<u>Load BTU hr</u>
Wall	1128	X0.05	X 17 ^o	959
Glass	390	X0.55	X 17 ^o	3,647
Door	21	X0.48	X 17 ^o	171
Roof	820	X0.08	X 53 ^o	3,477.
Infiltration	4000 cuft/hr	X0.0182	X 17 ^o	1,238
Diffuse				365
People				1,350
Lights				3,928
Appliances				<u>750</u>
				15,885 BTU hr

When nature presses hard, the response must be equivalent. When the pressure is more gentle, the response may be less distinctive.....²

4.0 Mechanical Supplements to Natural Forces

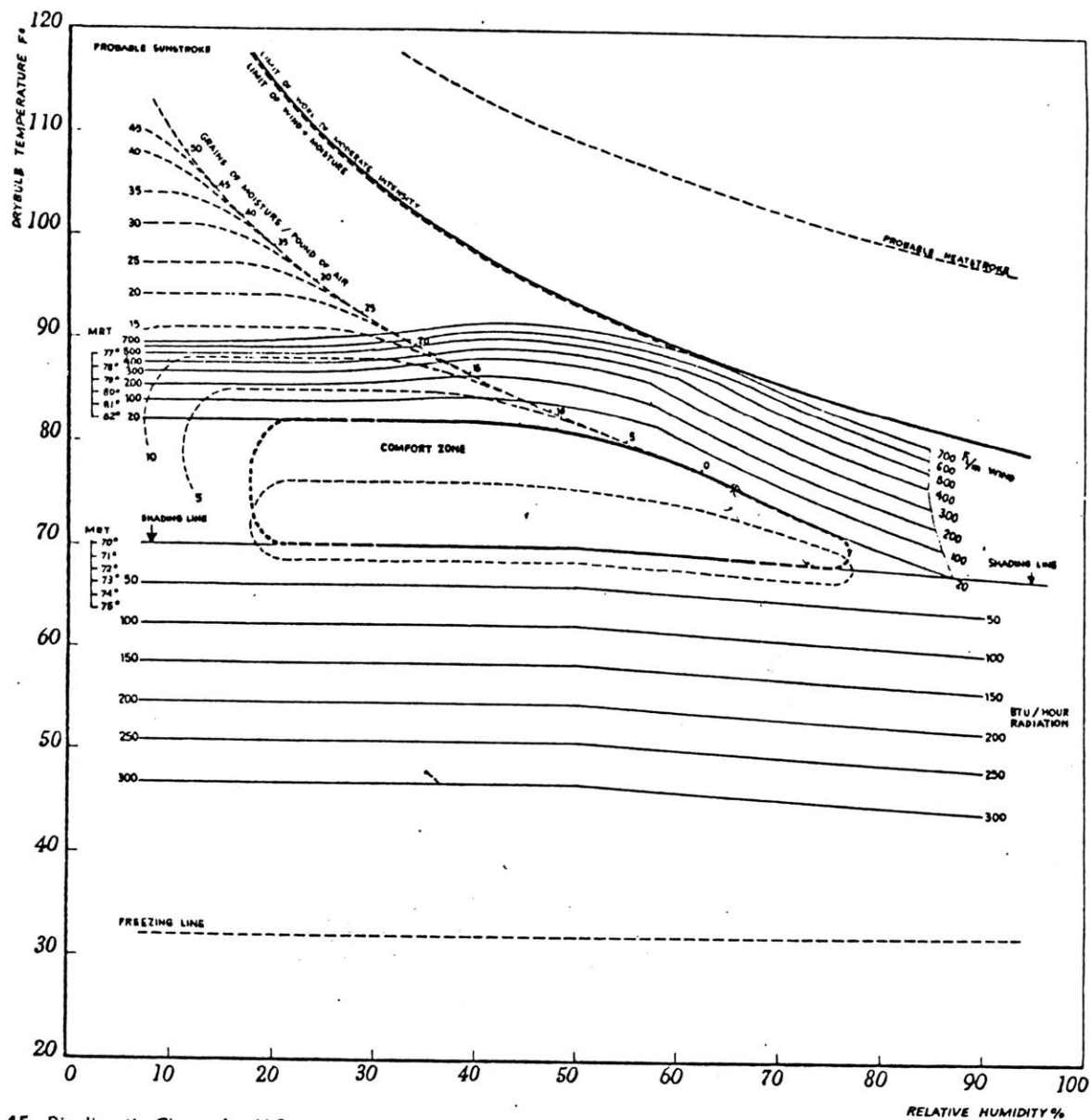
4.1 Review of Space Cooling and Dehumidification Systems

Since meteorological data for the Houston area show that difference between wet bulb and dry bulb temperatures (the wet-bulb depression) is comparatively small, the percentage of relative humidity is high. Natural ventilation is not sufficient for dealing with such high humidities. Referring to Table I, we see that in June the daily maximum temperature is 91.3°F at a relative humidity of 58%. Going to the Bioclimatic Chart (Chart I), we find that a wind speed of 700 feet/min. (8 mph) brings the inhabitant into the comfort zone and the humidity need not change. However, the mean wind speed for the month of June is only 6.3 mph. A simple fan can provide the necessary conditioning here. Again referring to Table I, for June a daily minimum temperature is 70.9°F at 92% relative humidity. Chart I shows that some dehumidification and some provision for sensible reheat is needed.

Conventional systems for air conditioning in this type of climate include: (a) the vapor compression system of refrigeration using electric power; (b) the absorption system of refrigeration using electricity, gas, kerosene, etc.

² Knowles, Energy and Form

Chart I

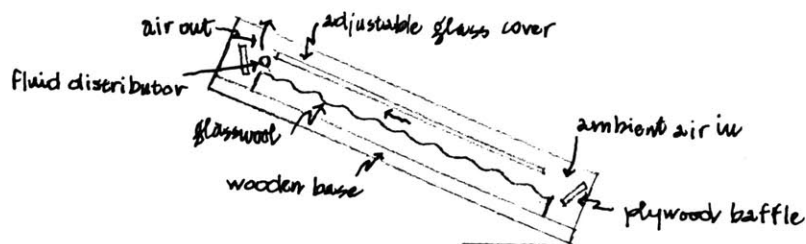


45. Bioclimatic Chart, for U.S. moderate zone inhabitants.

as the source of power; (c) steam jet refrigeration; (d) chemical absorption and adsorption method of dehumidification, using electricity, steam, gas, or any other source of direct heat. J. C. Kapur (India), in the Solar Energy Journal (January 1960), compared these systems as to refrigeration effect, power required for generator, booster ejector, or the regeneration process, gallons of water required, amount of power required for cooling and recirculation of condensed water, power for circulation and distribution of air, and applicability of solar power to each. He compared these systems roughly using the same dimensions as the large house in this project. Briefly, his conclusions were as follows: (1) Though the vapor compression system is the most efficient system of regeneration, solar energy as a source of power requires too many energy transformations. Such is also true for steam jet refrigeration; (2) solar energy utilization is more feasible for systems (b) and (d) above; (3) a system of using adsorption methods of dehumidification with chemical dessicants is favored, used with sensible cooling in a heat exchanger. For wet-bulb temperatures above 75°F solar heat can be used; (4) collector/reflector surfaces required for dew points above 62°F go beyond practical limits.

Mullick and Gupta (1973) devised "A method for desorption of water by solar heating the absorbent solution used for dehumidification of room air" also for the climate in India.

This is an attractive solution that uses a pump to circulate the brine solution and a fan to move the air across the



ILL. 9

blackened iron sheet of the collector. The brine is regenerated in a heat exchanger and recirculated to the collector-cum-desorber. The collector is about 117 square feet. The major drawback with this system where concerns application in Houston, Texas is that it cannot deal with the high humidities which occur when the sun is not out.

Evaluation of mechanical system for energy conservation goes beyond power input, efficiency, applicability of solar heat, or initial cost. Evaluation must cover each resource investment, its availability, cost and durability. Maintenance cost and durability are also evaluators of mechanical equipment. Breakdown potential, frequency of tune-ups, cleaning and ease of repair must be considered as well. A system's ability to work integral with other systems and its potential for reversal is also important.

In searching for an appropriate mechanical system to switch on when ambient conditions cannot be mitigated by natural ventilation/cooling, the simplicity of the Mullick/Gupta system must be kept in mind.

4.2 Using Lake Water as a Natural Energy Source

Everyone has experienced the phenomenon of moisture (condensation) forming on the outside of a glass of ice water. The glass here serves as a heat exchanger between the air and the ice chilled water.

The lake on which this project is sited has an annual maximum surface temperature of 82.5°F , an annual minimum temperature of 53.5°F , and an annual average surface temperature of 69°F . Lake temperature readings, taken at the site in the month of September, ten feet below the surface showed 60°F on one day at 12 p.m. and 61°F the next day at 1 p.m.

As the water temperature is regulated by the ice, in the above analogy, the water temperature of the lake near its bottom is regulated by the earth which has a mean annual temperature of 55°F and the sheer volume of lake water which exhibits high thermal inertia.

Cooling and dehumidification coils are the heat exchangers used most commonly in air conditioning systems. Water chilling is usually done by a refrigeration compressor which has a high first cost and high operating cost. Using lake water eliminates the need for this machine, but the temperature of the water is ten to twelve degrees higher than air conditioning industry standards for chilled water. This means that air at 93°F passing through the coils using a 60°F refrigerant will not get down to the 75°F , 50% R.H. industry comfort

standard. But a glance at Table I shows that comfort zone extends beyond industry standards from 80°F, 48% R.H. to 73°F, 77% R.H.

The National Association of Home Builders in a summary report of the Austin Air-Conditioned Village Project called "Residential Air-Conditioning," conducted tests to determine the relative importance air motion, relative humidity, air temperature, and mean radiant temperature in producing comfort. The test also sought to find the values which are desirable to maintain in each of the four elements. The findings are as follows:

<u>Element</u>	<u>Value</u>	<u>Number of Families Reporting Discomfort</u>
Air Motion:	Air in motion 50% R.H., 77°F	0
	Air still 50% R.H., 77°F	18*
Relative Humidity:	70 R.H. air in motion 77°F	1
	30 R.H. air in motion 77°F	0
	R.H. air in motion 77°F rapidly varying between	
	30 - 70%	18**
Air Temperature:	70°F air in motion 50% R.H.	14
	75°F air in motion 50% R.H.	3
Mean Radiant Temperature:	77°F air in motion 50% R.H.	0
	80°F air in motion 50% R.H.	5
	82°F air in motion 50% R.H.	18***

Outdoor temperature: 95°db

Each test was conducted twice: afternoon and before dawn

*complaints - stuffy, sweating, damp

**complaints - stuffy

***complaints - hot

These results, especially those on relative humidity (77°F, 70% R.H.), support the premise that the sensation of comfort can be realized at edge of the comfort zone. The system proposed in this thesis delivers air at 78°F, 70% R.H. from outside air at 93°F, 62% R.H.

4.3 The Supplementary System and How it Works

The proposed system simply pumps water up from three locations using three pumps, one pump serving eight or nine houses. Water is distributed via steel pipes laid underground to each house up through the floor slab and walls to the coils located in the attic (see Diagram I). A fan, working in suction, pulls the predetermined amounts of return and outside air from properly proportioned openings. The air is pulled over the coils, it is sensibly cooled and dehumidified and blown through supply ducts into the second level living spaces. The cool air falls naturally and moves to the first level spaces through short (1 ft) ducts located on the opposite side of the room. The air is then pulled through the first level spaces into a two story open space in each house to the return duct in the ceiling above. The water required is about 25,000 gals/day. After the water leaves the coil it flows back to the lake through

a wading pool, through showers in the community center, and through a garden stream.

COIL PERFORMANCE (daytime)

(July)

Entering air 93°F db, 62% R.H.

 t_{ldb} = leaving dry bulb temp.

Leaving air 78°F db, 70% R.H.

 t_{edb} = entering dry bulb temp.

ESHF = .80

 t_{adp} = apparatus dew point

$$Adp = 65^{\circ}\text{F}$$

$$CFM_{da} = \frac{15.845}{1.08 (15) (1-.30)} = \frac{15.845}{11.34} = 1397 \text{ cfm}$$

$$t_{ldb} = t_{adp} + BF (t_{edb} - t_{adp})$$

$$= 65 + .30 (93 - 65)$$

$$= 65 + .30 (28)$$

$$73.4^{\circ}\text{F} = 65 + 8.4$$

$$t_{edb} = (CFM_{oa} \times t_{oa}) + (CFM_{ra} \times t_{ra})$$

$$CFM_{sa}$$

$$= (278 \times 93) + (649 \times 78)$$

$$927$$

$$= 82^{\circ}$$

Coil Sizing

WATER COILS—WORK SHEET

.LETINS C-58, R-50 & RC-57

Job # Lake Cooled Housing
System # _____
Date DEC. 1975

1397 cfm (F 279.4 93° DB 77.5° WB) MIXTURE TEMPS.
(R 1117.6 78° DB 70.5° WB) 82° DB 76° WB = 59.43 Btu/# AIR
TH LEAVING COIL = 31.51 Btu/# AIR
TH EXTRACTION = 27.92 Btu/# AIR

ROOM S = 15,845 Btuh ÷ (1.087 x 1397 cfm) = 10° TEMP. DIFF.
DB LEAVING COIL = 83°

ROOM L = 1,600 Btuh TH AT ROOM WB = 34.51 Btu

ROOM T = 17,445 Btuh ÷ (4.45 x 1397 cfm) = 3.0 Btu
TH LEAVING COIL = 31.51 Btu
WB LEAVING COIL = 66.85°

► 27.92 TH EXTRACTION x 4.45 x 1397 cfm = 173,569 Btuh (INCL. FRESH AIR)

WATER QUANTITY = 173,569 Btuh = 17 gpm (24,480 gals/day)
500 x 20° WATER RISE

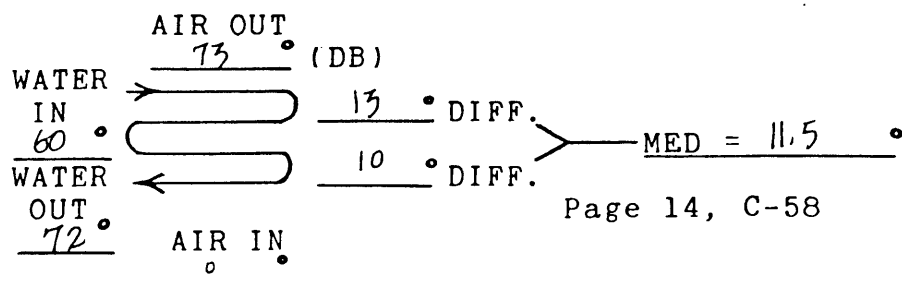
UNITS FOR 500'/MIN. APPROX. = UNITS 12 T.F. 2.63 T.L. = 4 TOTAL SQ. FT. F.A.

AIR VELOCITY = 1397 cfm = 350 '/MIN.
Sq. Ft. F.A. } K = 500

WATER VELOCITY = 17 gpm x 1.235 = 2 '/SEC.
"C" x 12 TOTAL TUBES)
ACROSS FACE) Page 11 or 22, C-58

SH RATIO = (DB (IN) 93 - DB (OUT) 73 x .241 = .20 $\frac{SH}{TH}$

→ 27.92 TH

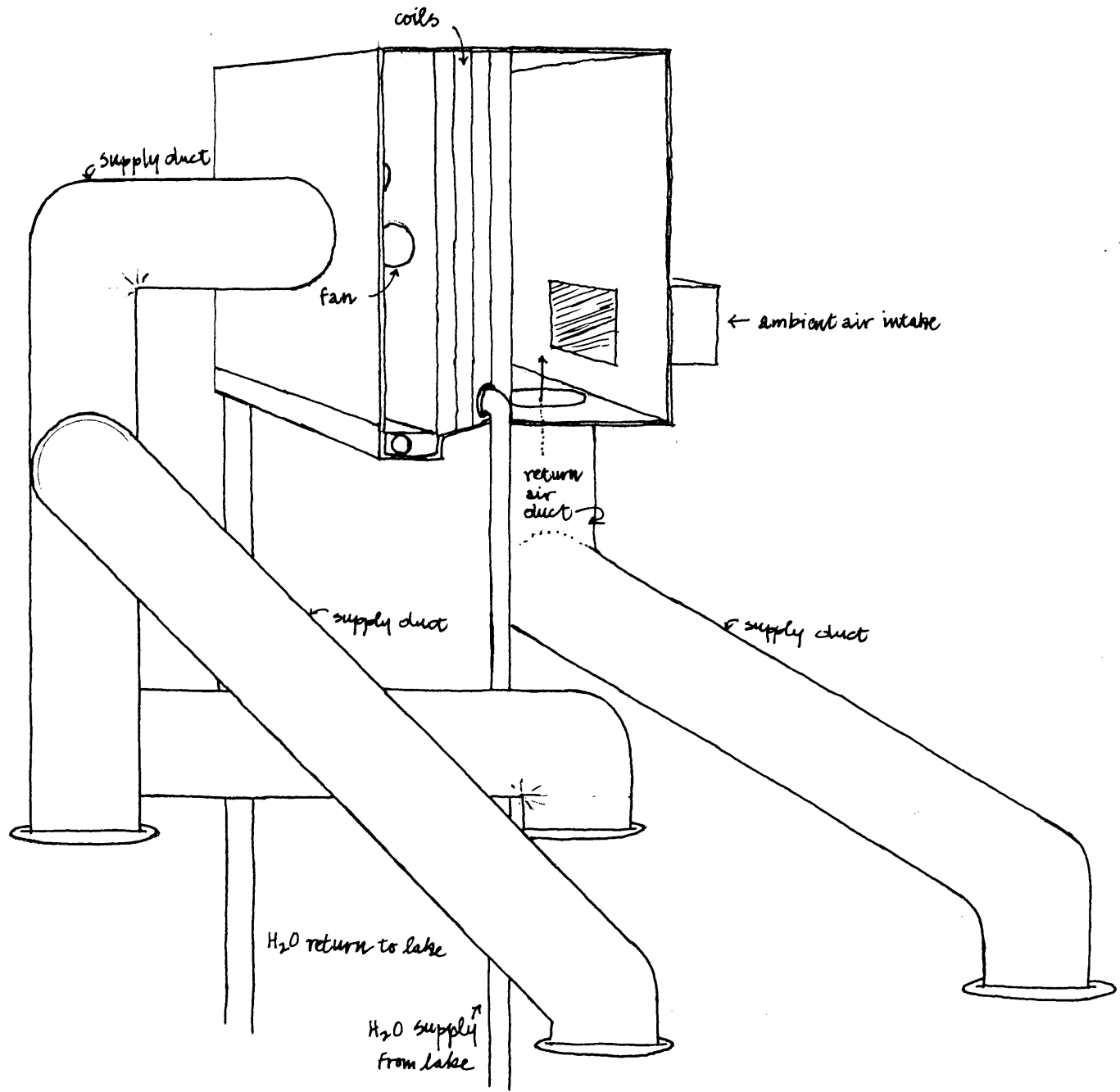


(FULL CIRC., C = 1.0
(1/2 CIRC., C = 0.5
(1/3 CIRC., C = 0.33
(DOUBLE CIRC., C = 2.0

WS = 173,569 Btu/Hr = 7.5 ROWS
 $\frac{500}{(K)} \times \frac{11.5}{(M.E.D.)} \times \frac{4}{(Face Area)}$

Diagram IV

SYSTEM DIAGRAM



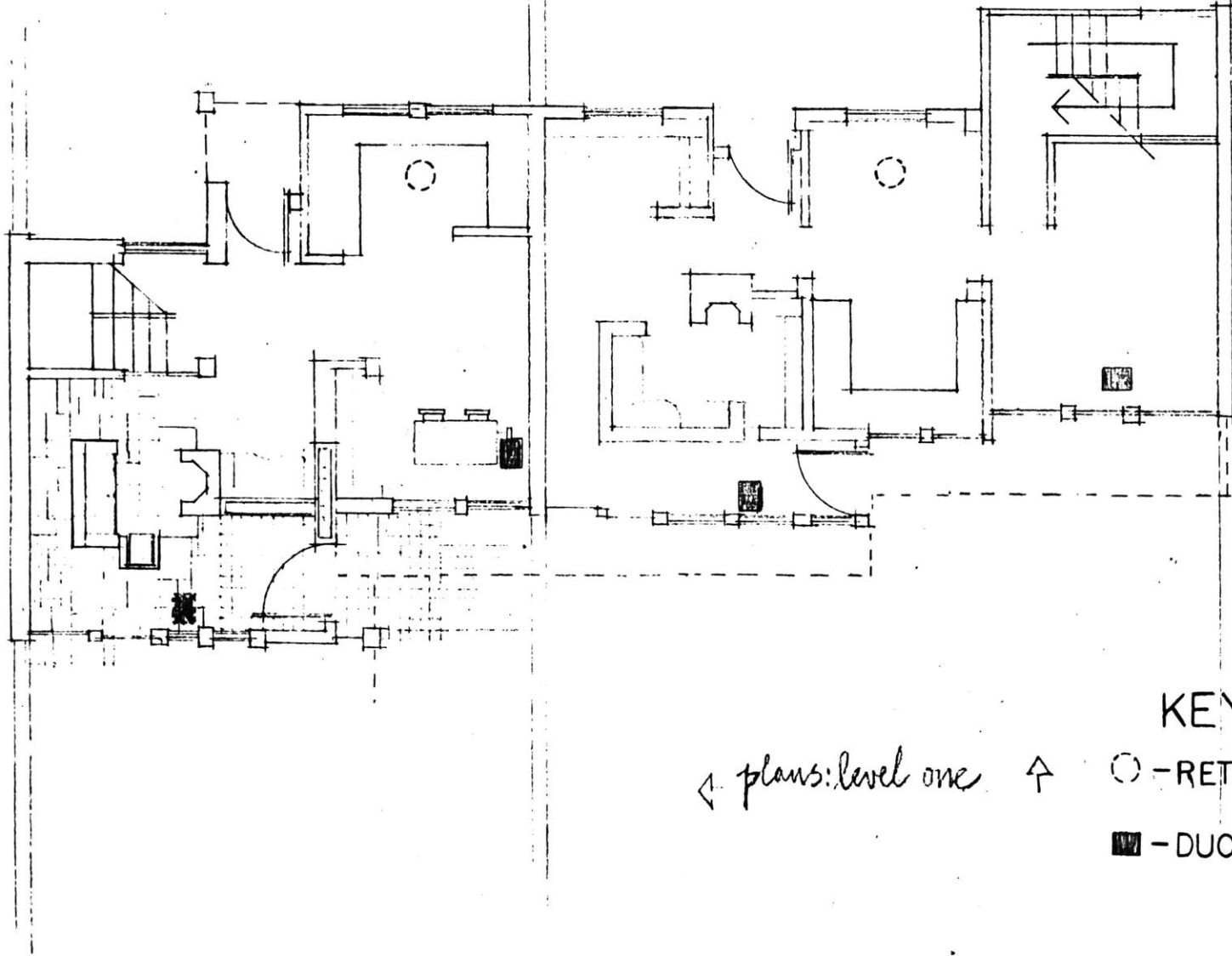
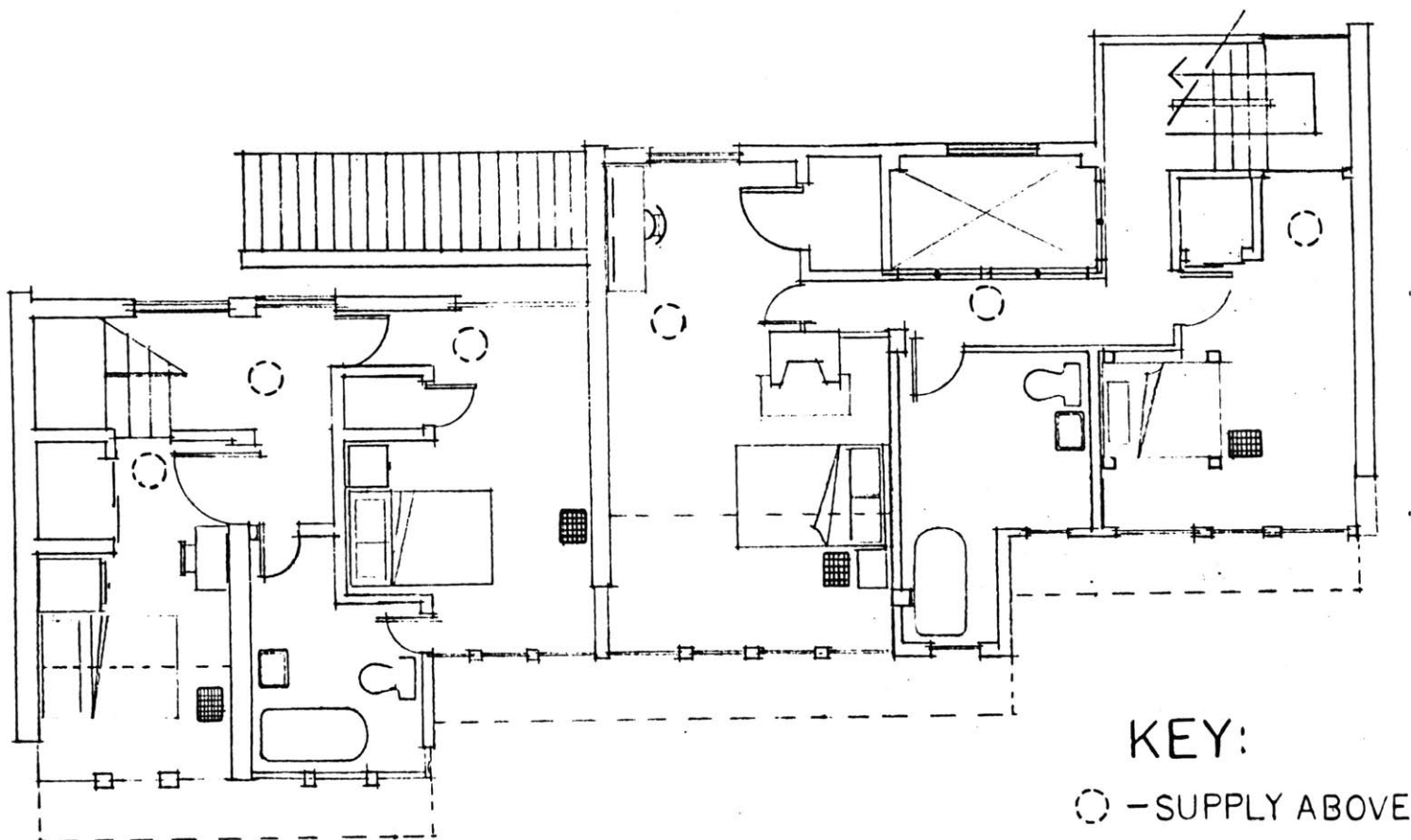


Diagram Vb
Conditioned Air Distribution



plans: level two

Diagram Vc
Conditioned Air Distribution

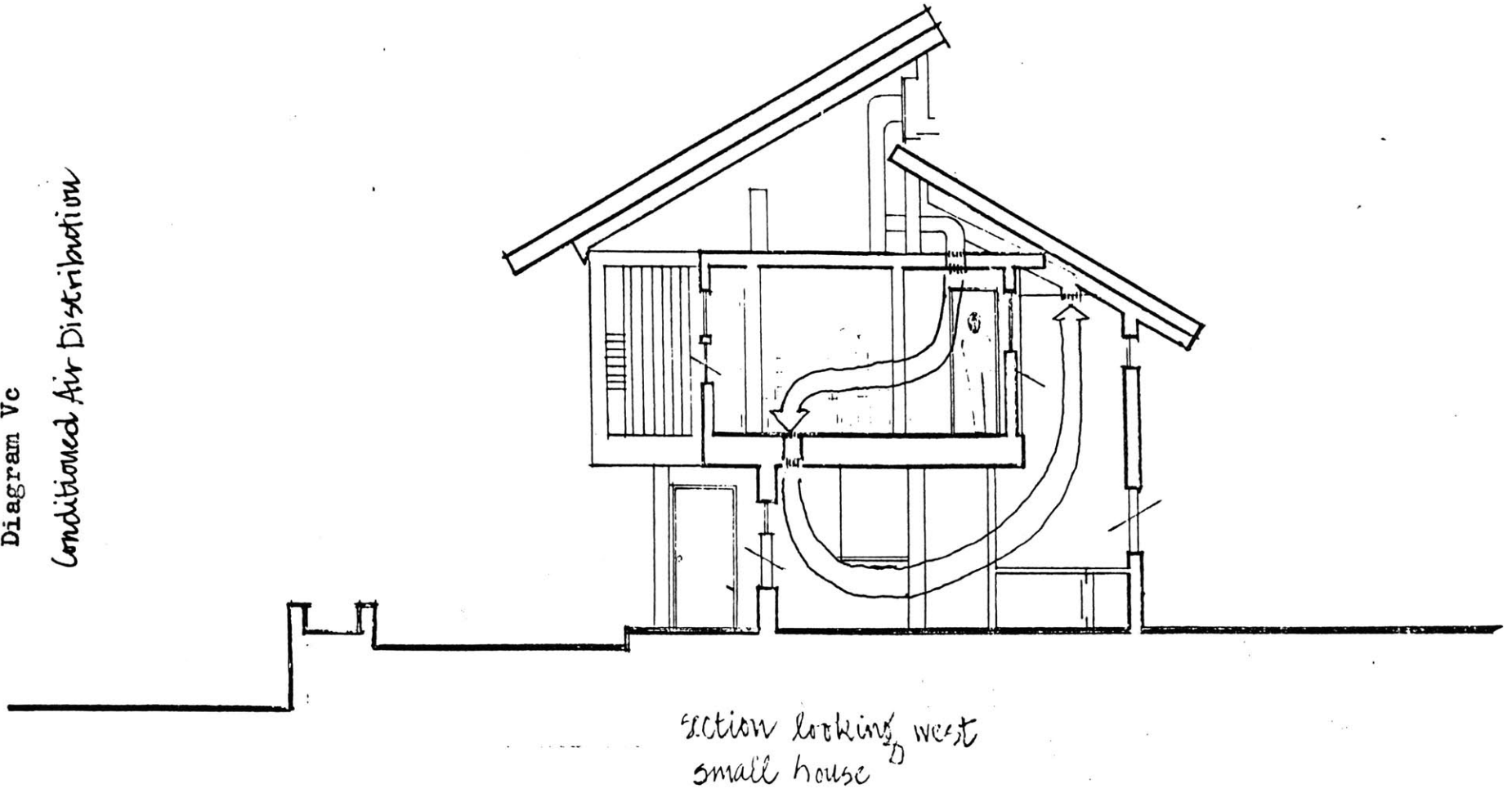
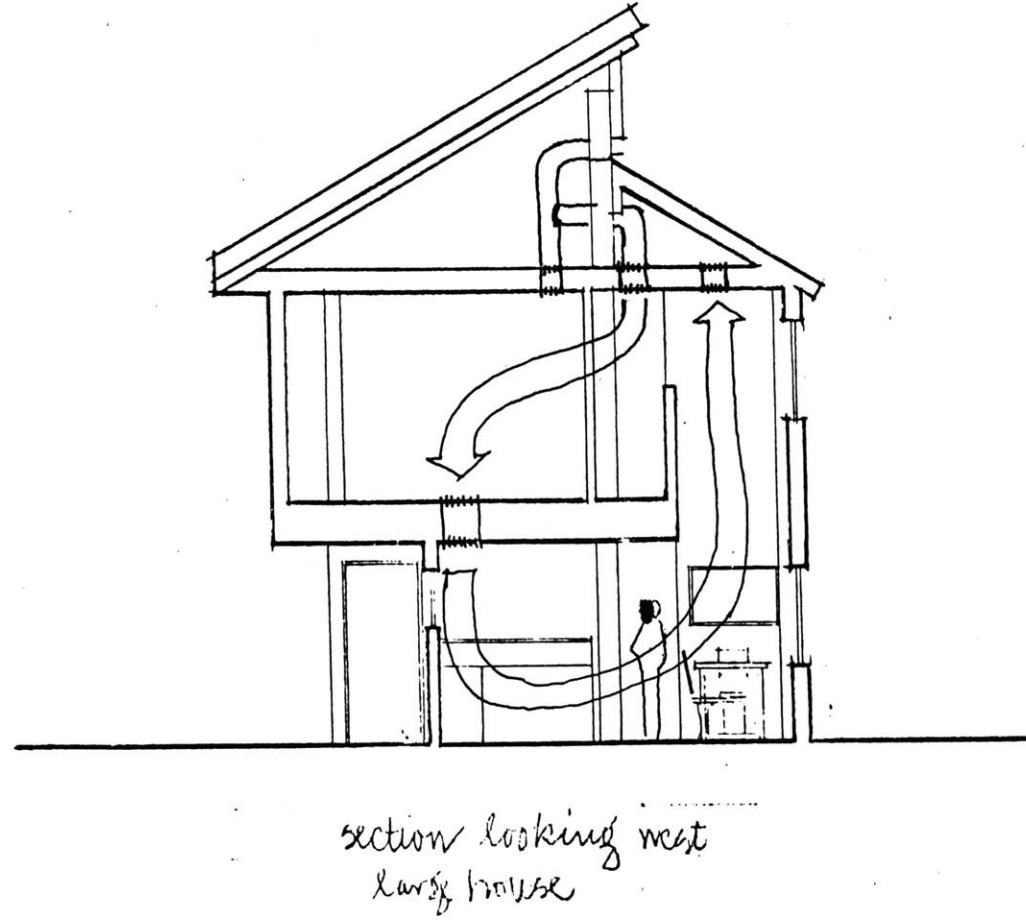


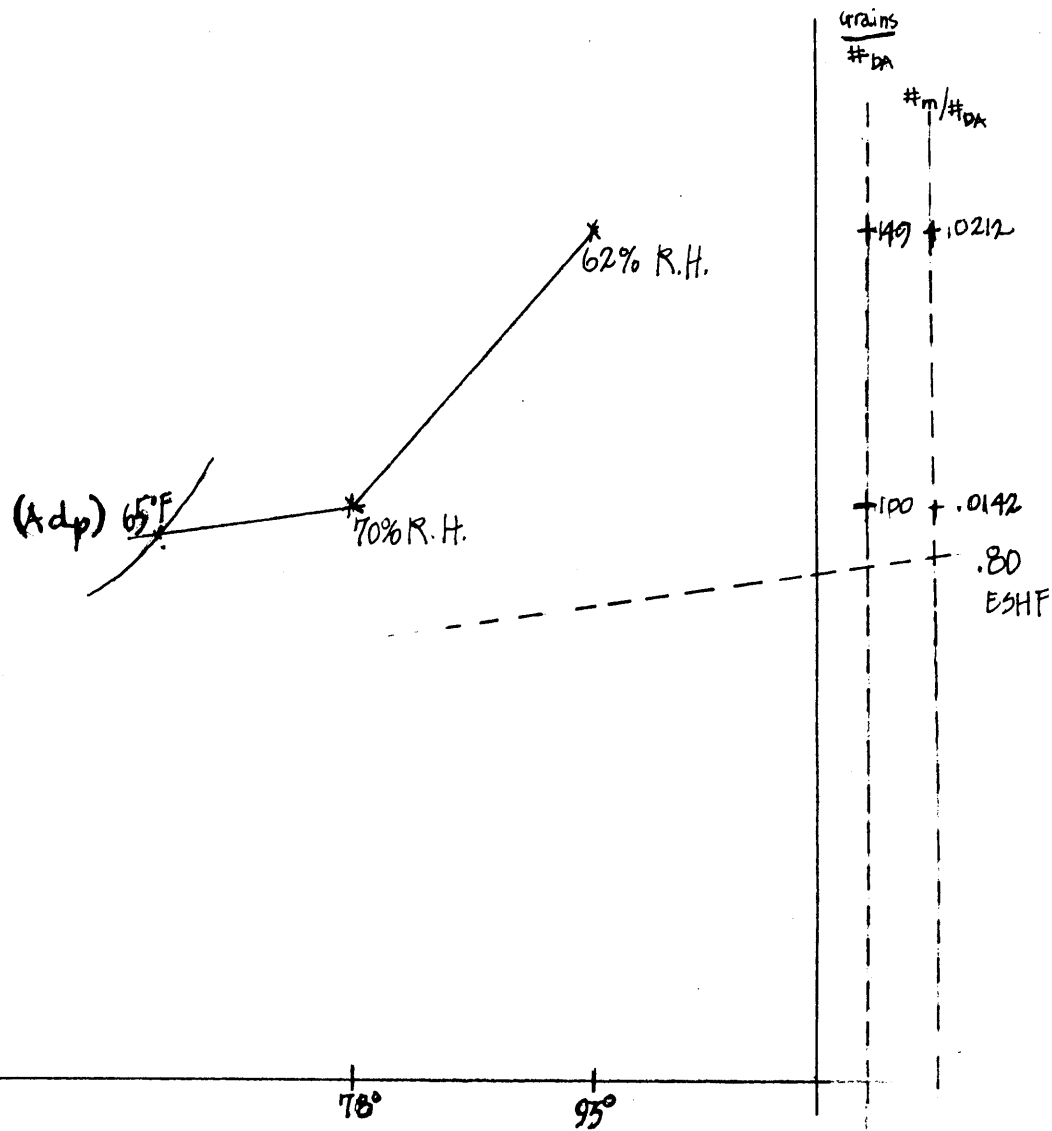
Diagram Vd
Conditioned Air Distribution



Performance Curve

Chart II

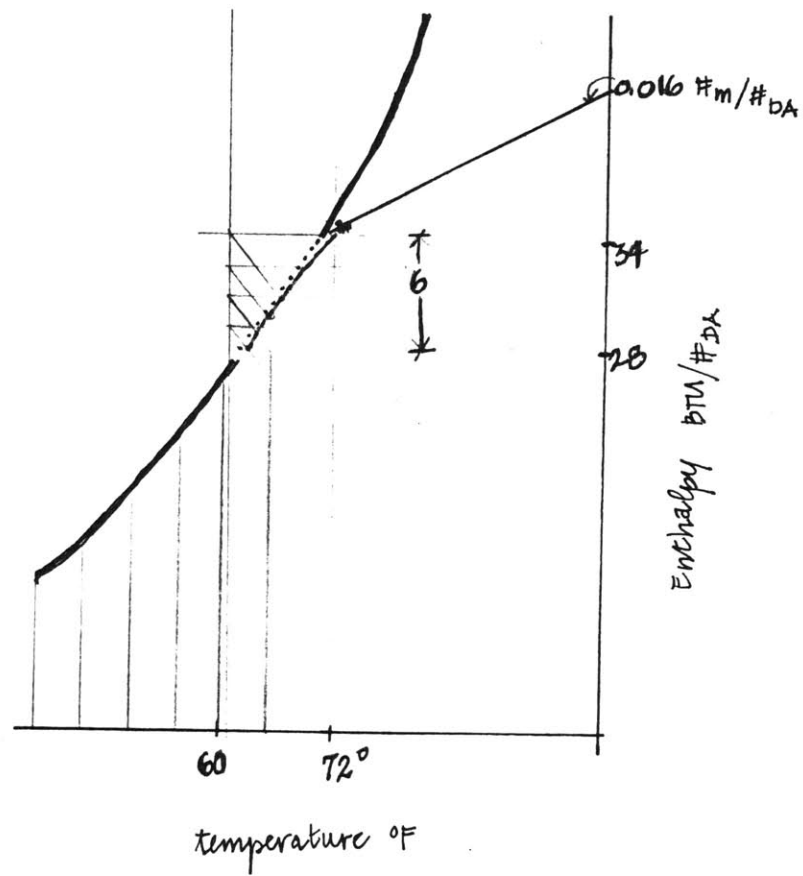
(daytime)



Performance Curve

Chart III

(nighttime)



(low dry bulb temp. indicates need for reheat)

SYSTEM COMPARISON: ENERGY COST/ 1 PEAK DAY

TABLE IV

Proposed System	Fan Coil System	Central Air Conditioner
Fan(s)	Fan(s)	(24,000 BTUh) from Sears Catalog
2-1000 CFM 6,335 watts	2-1000 CFM 6,335 watts	Energy consumed 81,600 watts (includes blower wattage)
Pump (17,280 gals/day)	Pump	
3/4 hp 27,109 watts	3/4 hp 27,109 watts	
18 gpm	Refrigeration compressor 7,992 watts	
33,444 watts	41,436 watts	81,600 watts
EQUIPMENT COST		
Fans 79.50	Fans \$159.00	Fan
(79.50 each)	Pump 500.00	8 - 6" Ducts
Pump $\frac{\$500}{8}$	Refrigerator compressor 800.00	Coil and condenser
Housing installation 62.50	Duct work	
Coil (installed) 300.00	*Electric Reheater 200.00	
Duct work (inst) 185.00		
+ 10% (insula- tion) 150.45		
Piping <u>440.00</u>		
\$1,217.45	<u>\$1,659.00</u>	<u>600.00</u>

PRELIMINARY CALCULATIONS

$$d = \frac{r(1-r)^N}{(1+r)^n - 1}$$

$$= \frac{(0.08) (1+0.08)^{20}}{(1+0.08)^{20} - 1}$$

$$= \frac{(0.08) (4.7)}{(4.7-1)}$$

$$= \frac{0.376}{3.7}$$

$$= 0.10$$

$$a = \frac{1 + g}{1 + r}$$

$$= \frac{1+0.12}{1+0.08}$$

$$= 1.03$$

$$\frac{1}{d} = \frac{a(a^N - 1)}{a - 1}$$

$$= \frac{(1.03) (1.80-1)}{1.03-1}$$

$$= \frac{0.82}{0.03}$$

$$= 27.5$$

FANS: Assuming a performance factor of 7, duct pressure of
 $3/8$ in H_2O or 1.8 lb/sf

POWER: (24 hour operation) = 24 hrs. x 1.8 lbs/sf x 927 CFM x 7
 x 0.02260 watts/ft. - lb./min.
 = 6335 watts @ \$ 0.03 /kwh
 = 6.3 kwh \$11.34 60 day oper-
 ation:

PUMP: 24 hour operation 17,280 gals, 50 ft head

POWER: = 24 hrs x 50 ft x 17,280 gal/24 hrs. x 8.33 lbs/gal
 x 1 hr/60 min x 0.2260 watts/ft - lb/min.
 = 27,109 watts @ \$ 0.03/kwh
 = 27.1 kwh \$48.78

BENEFIT/COST COMPARISON OF PROPOSED SYSTEM AND
CENTRAL AIR CONDITIONER FOR 60 DAY USE

$$\frac{\text{Benefit}}{\text{Cost}} = \frac{\text{Annual energy saving}}{\text{Additional capital cost} \times d}$$

$$d = 0.10$$

$$\begin{aligned} \text{Annual energy savings} &= [(4896) (2.5) - (2010) (2.5)] \quad [\$0.03] \\ &= (12,240 - 5025) (\$0.03) \\ &= \$216.45 + \$100 \text{ (maintenance)} \\ &= \$316.45 \end{aligned}$$

$$\frac{\text{Benefit}}{\text{cost}} = \frac{\$316.45}{4617.45 \times 0.10} = 5.125 \quad \frac{1}{d} = 27.5$$

Present Worth:

$$\frac{\text{Benefit}}{\text{cost}} = \frac{316.45 \times 27.5}{\$617.45} = 14.09$$

$$\text{Years to repay} = \frac{20 \text{ years (life of coil)}}{14.09} = 1.4$$

5.0 Conclusion

This project investigated the effectiveness of using natural forces for producing comfort through proper siting and building design.

Testing was done using models to check the design (of window openings and interior partitions which were determined by the analytical method) for natural ventilation performance.

The effect of the design for natural heating was measured analytically using design dimensions for walls, windows, and also from solar radiation data for 30° north latitude.

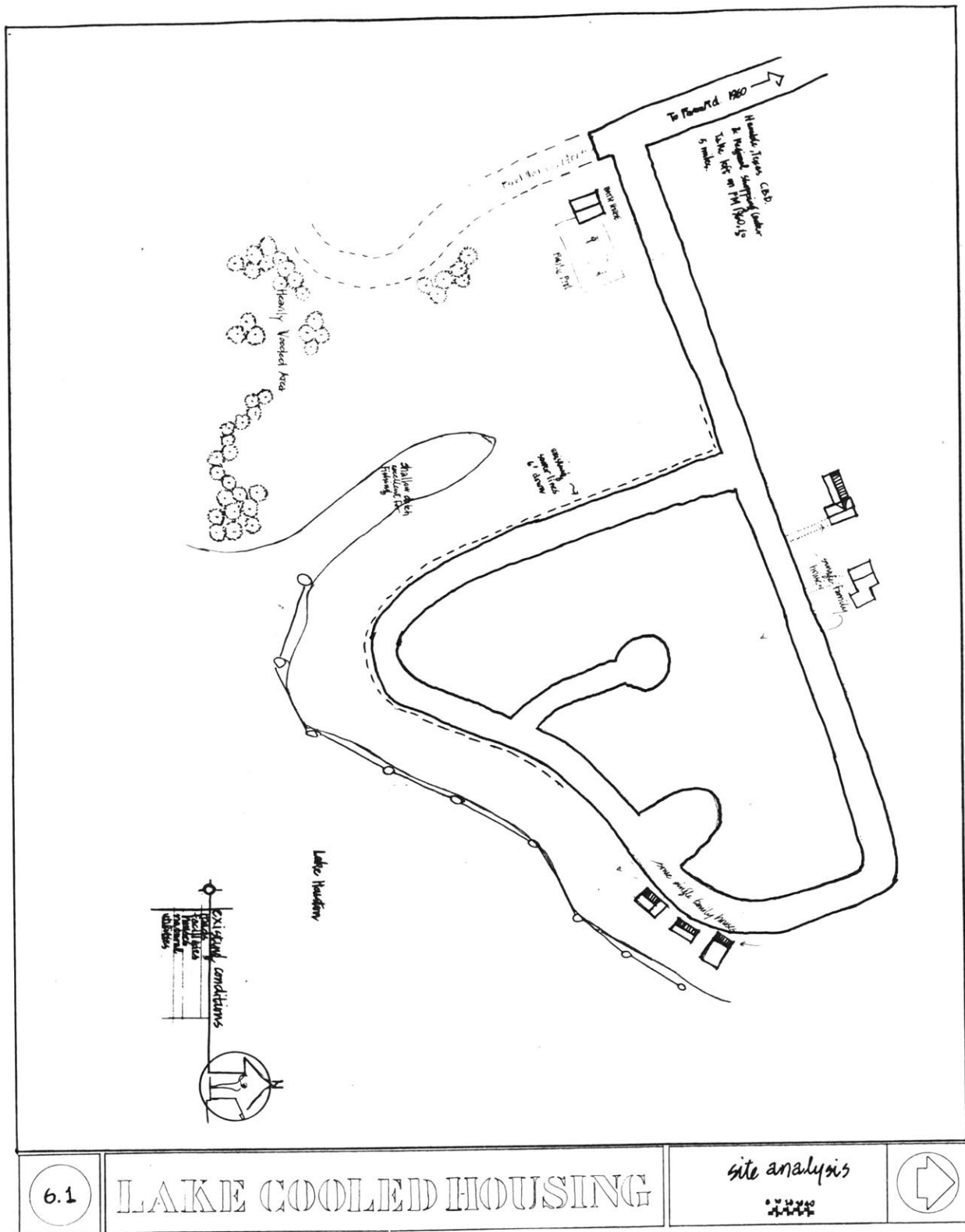
A supplementary system for mechanical assist of natural cooling forces was developed from conception, through sizing, and on to comparison with conventional systems as to first and operating costs. Life costing analysis was also done to determine benefit/cost and payback period.

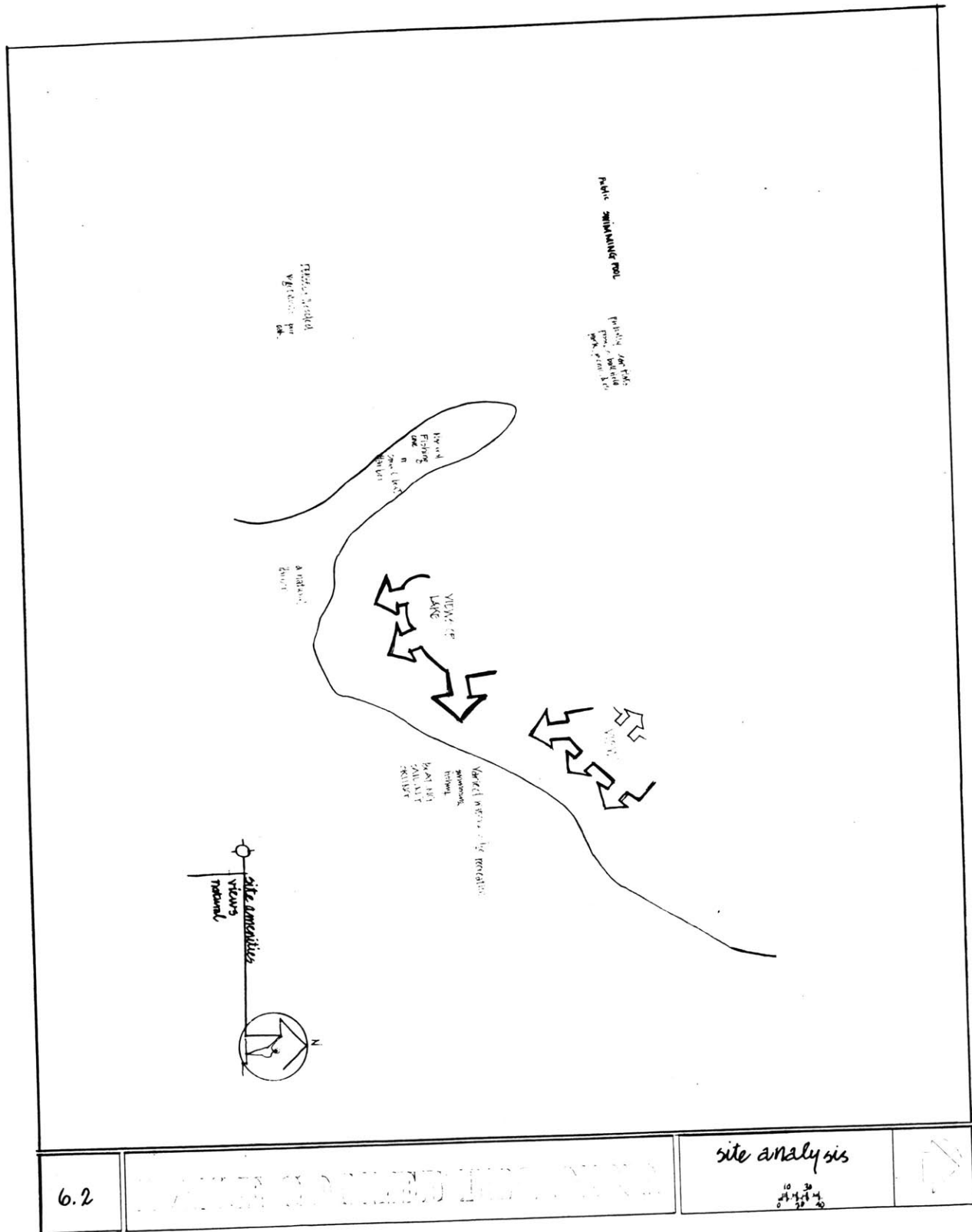
The global results are as follows:

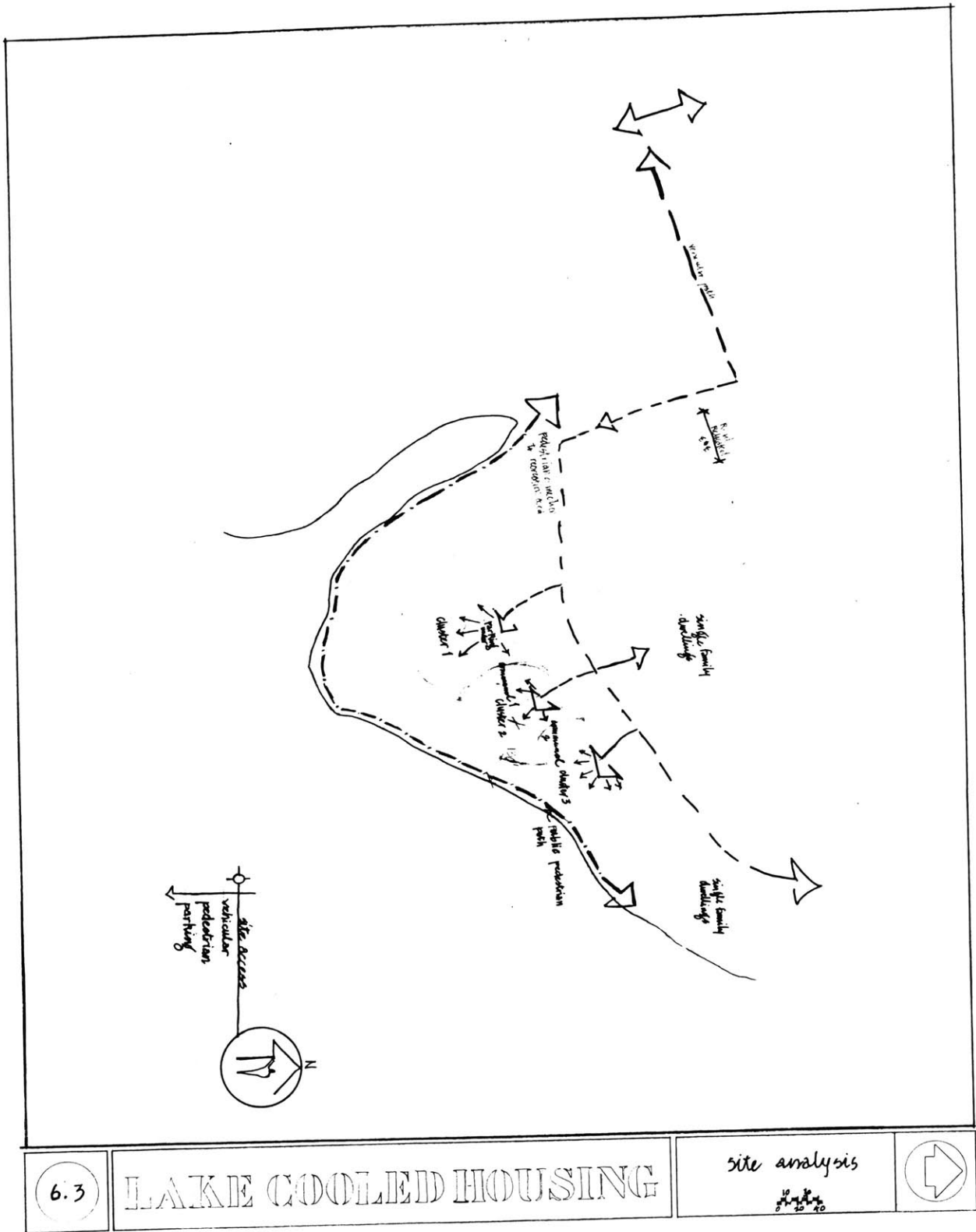
- (1) During winter months a net positive flow is realized with 50% glazing on the southeast faces, and 30% glazing on the north. Some heating will be required in the houses with south and southwest orientations.
- (2) During spring and early summer (June only) natural cooling is effective since wind velocities are sufficient and because a thin building section is used along with open planning of interior spaces and large leeward openings.

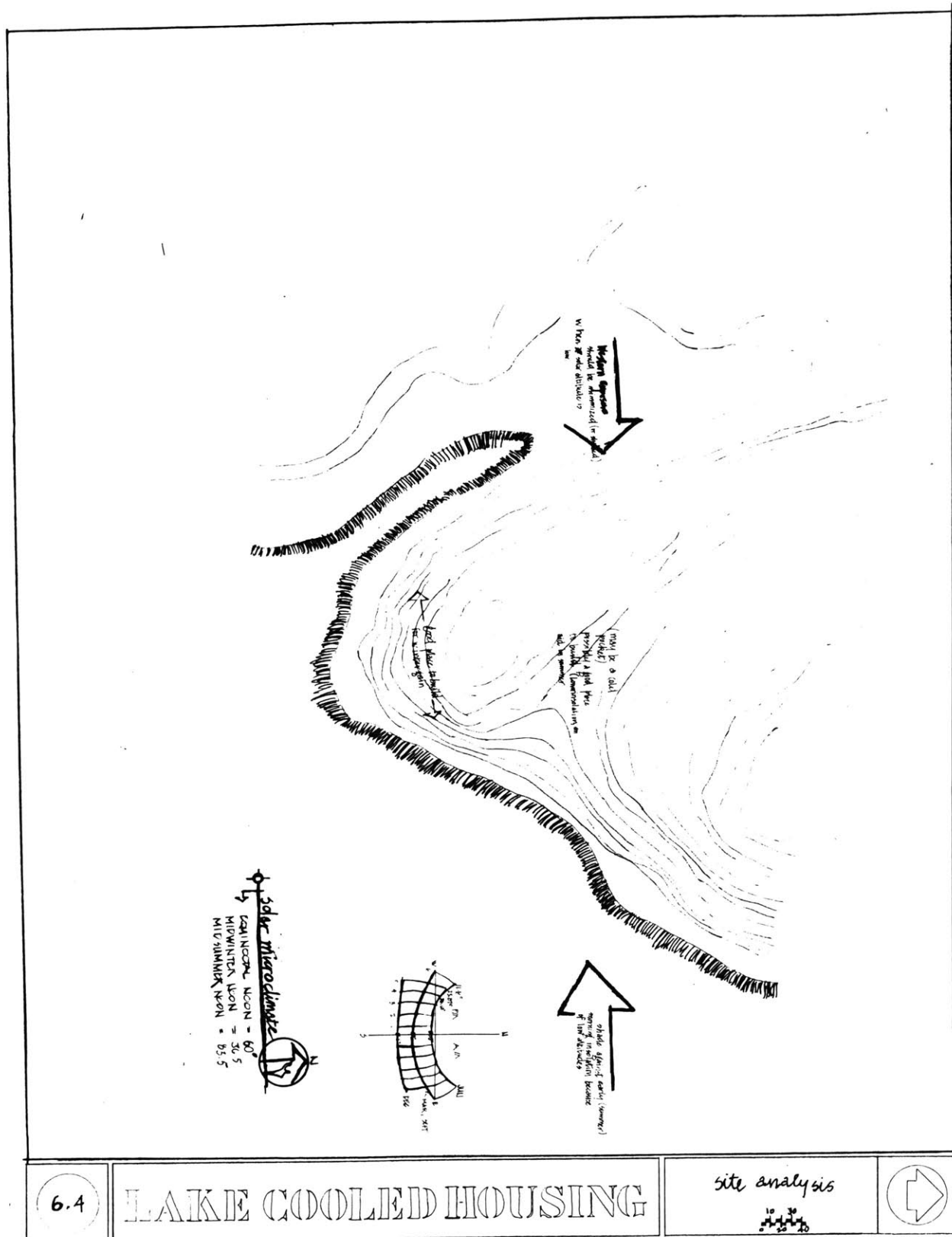
(3) The proposed system compares favorably with the fan coil system on a first cost basis since each system costs the same. The proposed system, however, offers the advantage lower energy costs (20% less/season), the elimination of the refrigeration machine, a constant maintenance problem, and is generally maintenance free except for replacing filters and drainage at the end of the season.

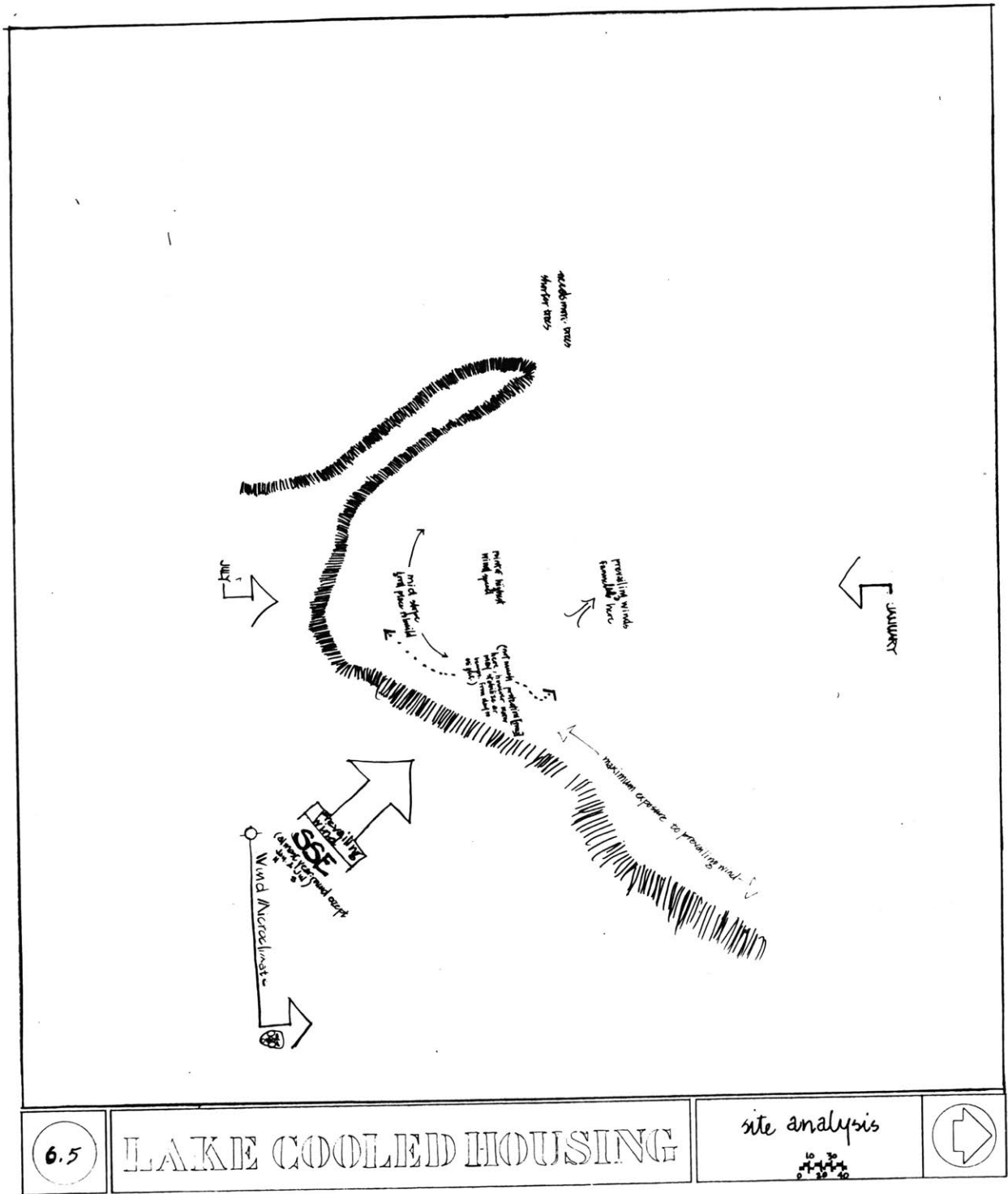
In comparison with the central air conditioner the proposed system consumes 40% less energy/season but costs a little more than twice as much. The ratio of energy savings to additional cost is an encouraging 5.1. The pay-back period is 1.4 years.

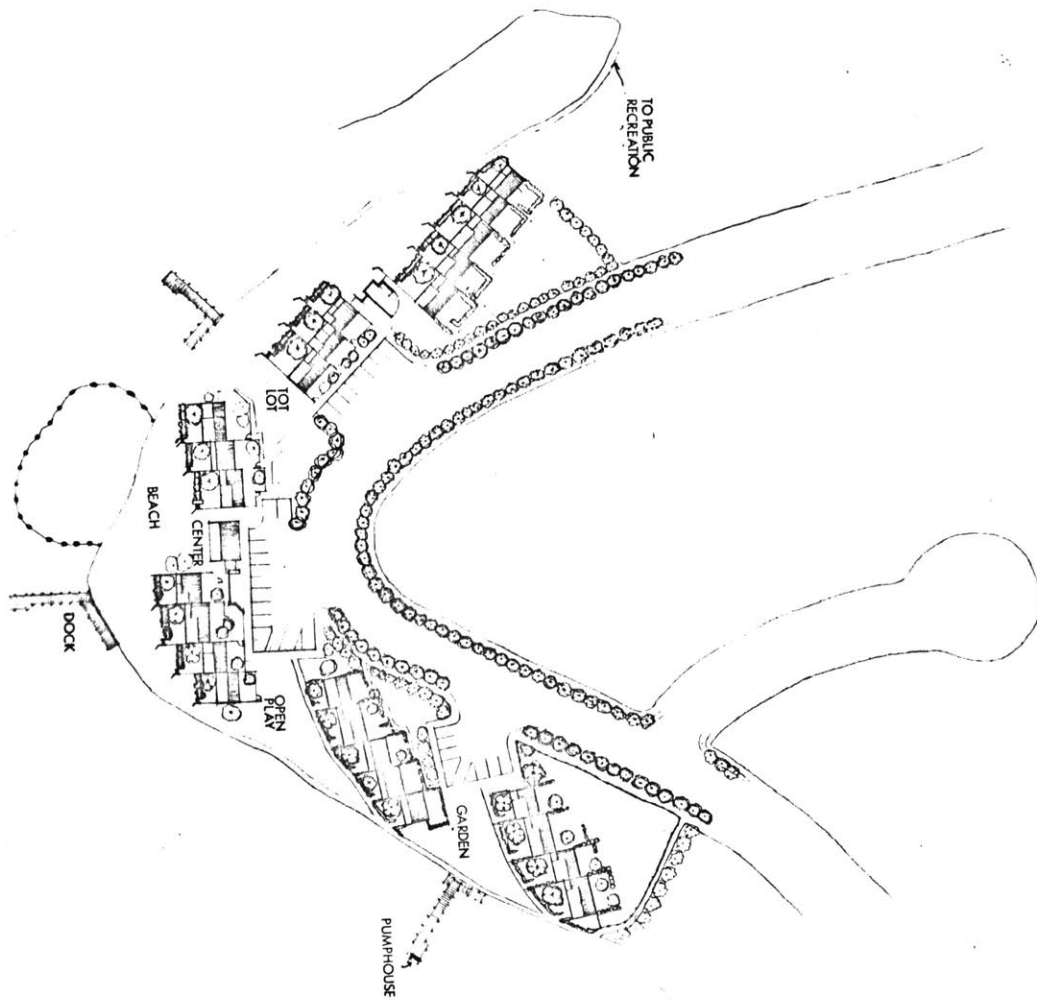




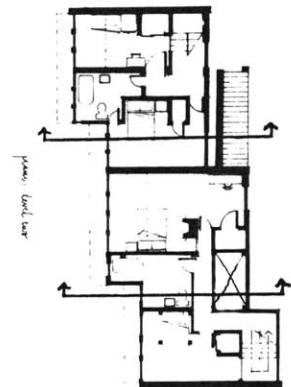
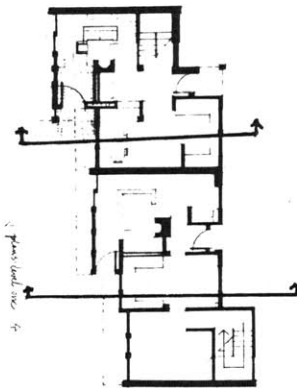
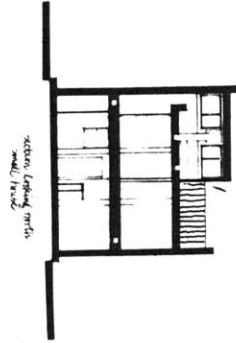
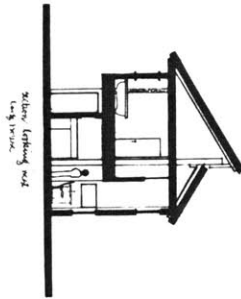
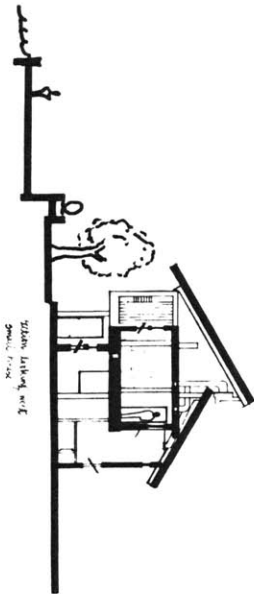








<div data-bbox="235 1690 308 1753" data-label="Text"> <p>6.6</p> </div>	<div data-bbox="332 1680 990 1753" data-label="Section-Header"> <h1>LAKE COOLED HOUSING</h1> </div>	<div data-bbox="1047 1669 1161 1711" data-label="Text"> <p>site plan</p> </div> <div data-bbox="1112 1722 1177 1753" data-label="Image"> </div>	<div data-bbox="1266 1659 1347 1743" data-label="Image"> </div>
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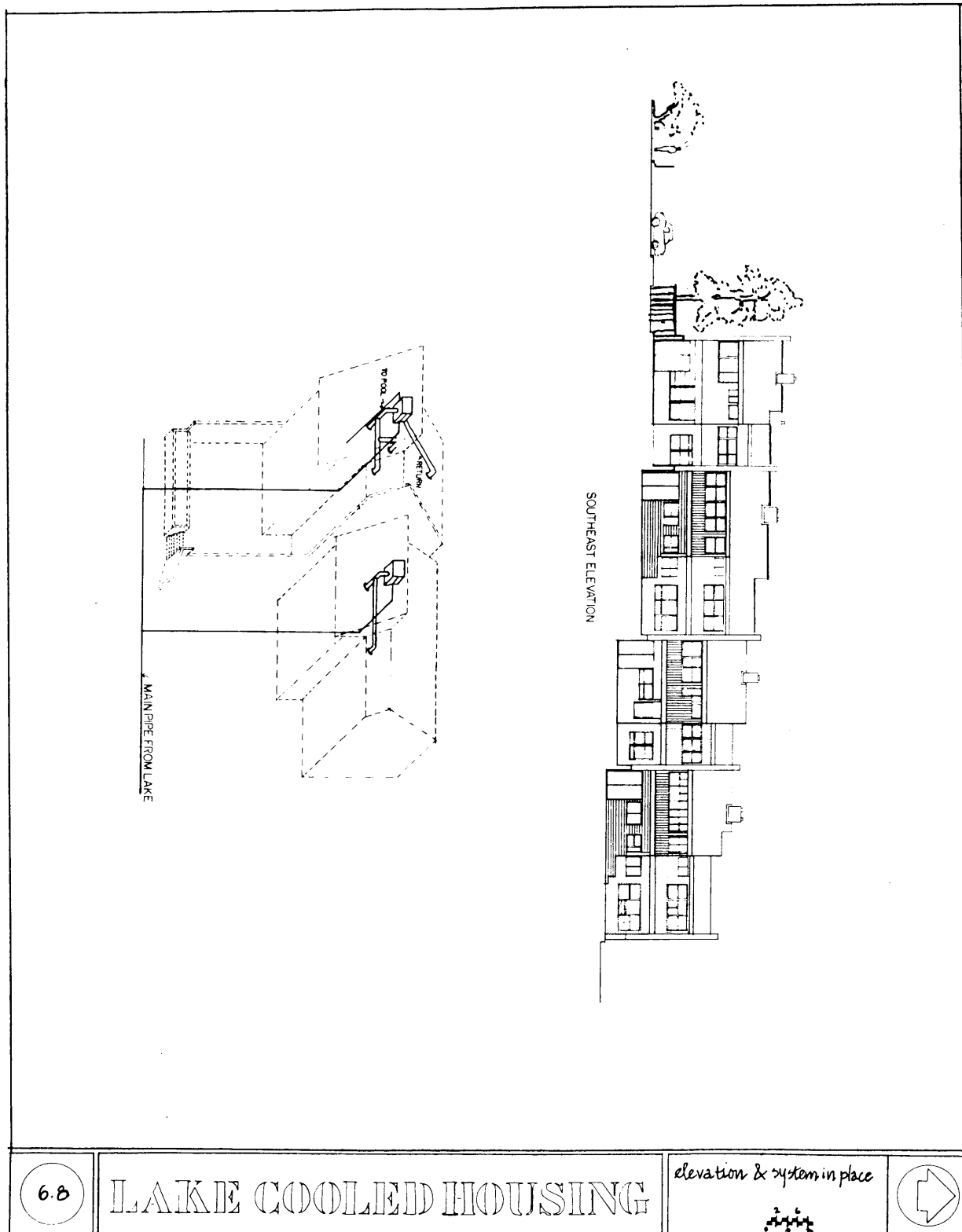


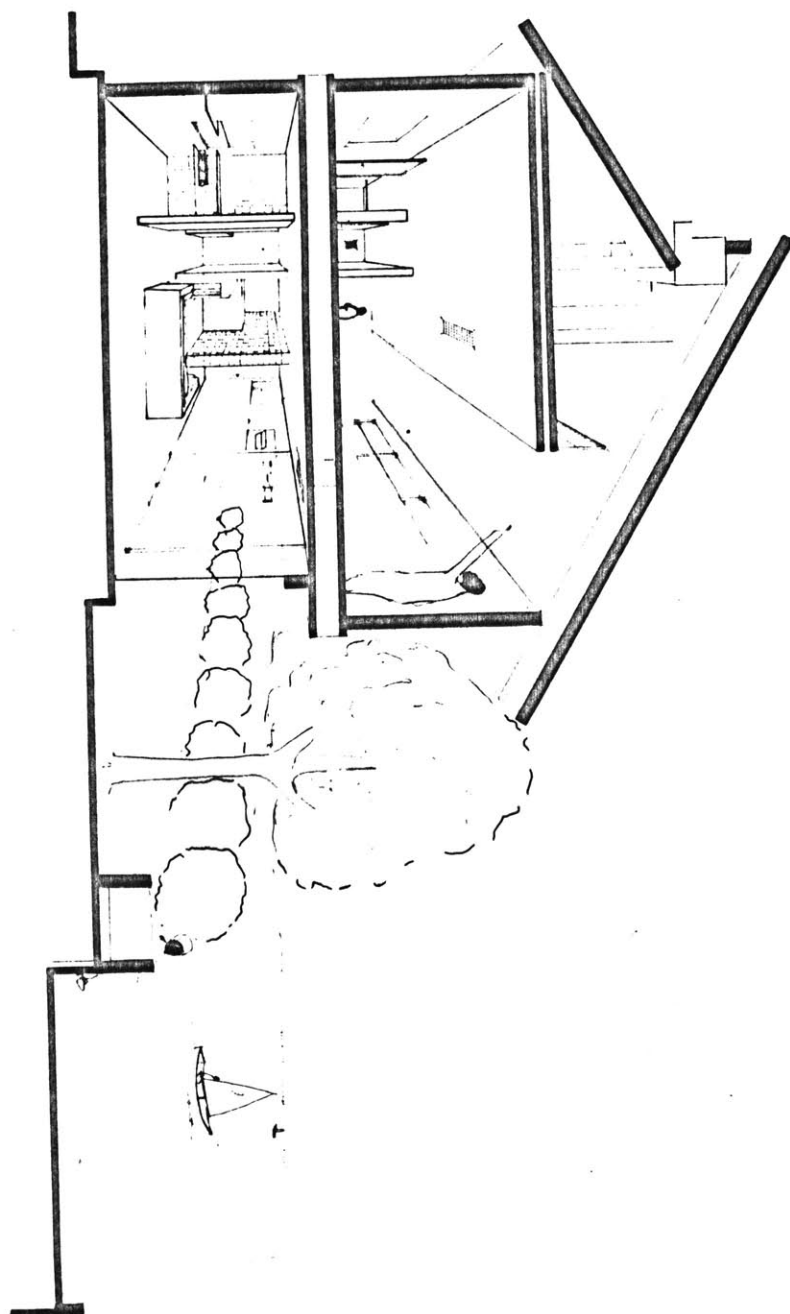
6.7

LAKE COOLED HOUSING

plans & sections







6.9

LAKE COOLED HOUSING

perspective

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## APPENDIX

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## USEFUL CONVERSION FACTORS:

1 BTU/hr = 0.2930 watts

1 hp = 745.7 watts

1 ft-lb/min = 0.02260 watts

1 lb dry air = 13.6 cu. ft. (cf) at 75°F, 50% R.H.

1 gal H<sub>2</sub>O = 8.33 lbs.

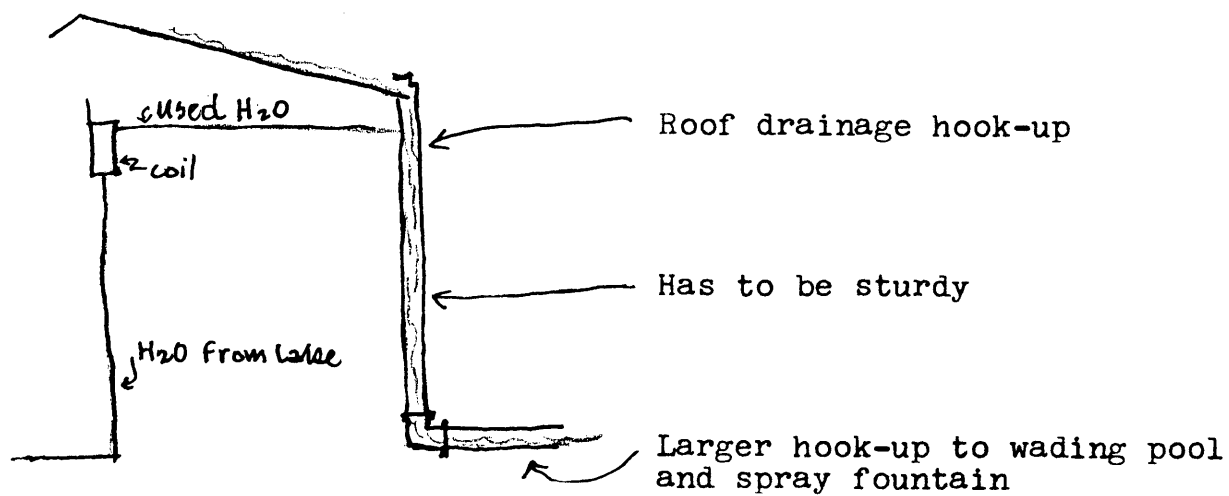
1 cu. ft. H<sub>2</sub>O = 62.4 lbs.

## WATER REMOVAL

Rain 1. roof  
2. ground surface

Cooling water

Condensed water



## Solid waste removal at Atascocita Community

Tertiary treatment

Central treatment plant located at southwest part of site  
on Atascocita Road.

The effluent flows into Greens Bayou

Sludge (bed) is carried off to sanitary fill dumps



Removal of moisture

49 Grains/# dry air

$\frac{0.0070 \text{ \#moisture/\# dry air}}{\text{to be removed}}$

46.4 BTU/#DA

34.6 BTU/#DA

11.8 BTU/#DA Heat removed/#DA

- conduction -  
55620 cfh = 5 air changes/hr

927 x 0.30 = 278 outside air

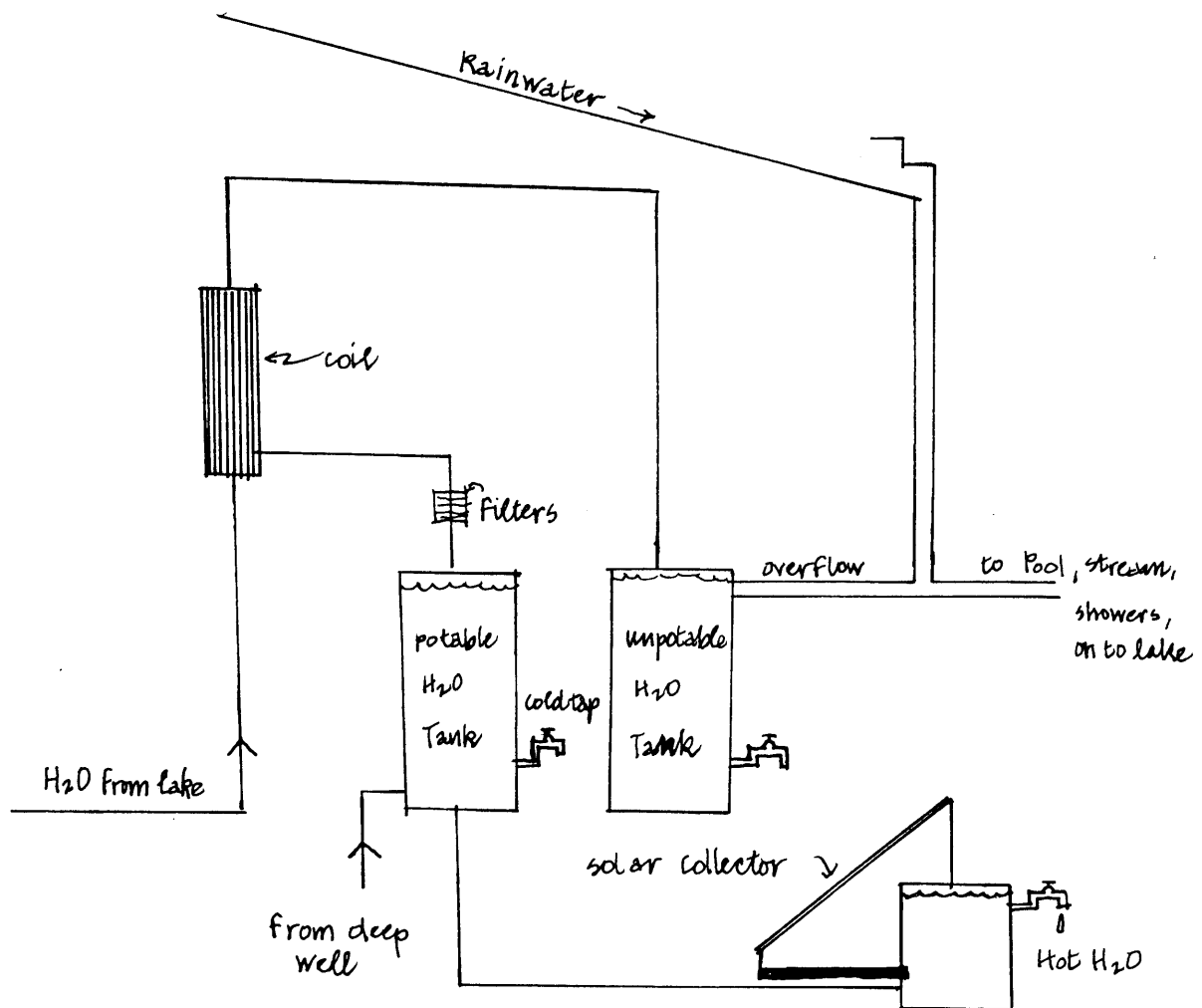
$\frac{10,508 \text{ /h}}{11.8/\text{\#DA}} = \underline{891 \text{ \#DA/hr to be removed}}$

1cf - 0.075 lbs.      891 #DA/hr x 0.0070 #M/  
= 6.2 # moisture/hr (condensate)

## COST OF WATER DISTRIBUTION

|                          | COST        |
|--------------------------|-------------|
| 300' - 3" pipe @ \$9.80  | \$3000.00   |
| 720' - 2" pipe @ \$5.70  | \$4104.00   |
| 840' - 1½" pipe @ \$4.45 | \$3893.75   |
|                          | <hr/>       |
|                          | \$10,997.75 |

Developer  
Pays?



## SYSTEM INTEGRATION

## Solar Hot Water Heater

Solar Radiation on vertical wall facing south on January 21

$$= 1115 \text{ BTU/SF/DAY}$$

## Total Solar Radiation

$$= (\text{Direct Solar Radiation} \times \cos 40^\circ) + \text{Diffuse Solar Radiation} \\ (\text{10\% of Direct})$$

$$= (1115 \times \cos 40) + 111.5$$

$$= (1115 \times 0.643) + 111.5$$

$$= 717 + 111.5$$

$$= 828.5 \text{ BTU/SF/DAY} \times 0.50 \text{ (cloud cover)} \times 0.70 \text{ (collector efficiency)}$$

$$= 290 \text{ BTU/SF/DAY} = Q \text{ useful}$$

$$Q \text{ useful} = M C_p (T_{\text{out}} - T_{\text{in}})$$

Cp = Specific heat of water

M = Mass Flow

$$M = \frac{Q \text{ useful}}{4 (T_{\text{out}} - T_{\text{in}})} \\ = \frac{290}{(1)(140-58)}$$

$$= 3.4 \text{ lb/SF/Day}$$

Water Required:

$$\begin{array}{r} 150 \text{ gal/family/day} \\ \text{lbs} \\ \times 8 \text{ gal} \\ \hline 1200 \text{ lbs./ Family/ day} \end{array}$$

$$\frac{1200 \text{ lbs/ day}}{3.4 \text{ lbs /SF/day}} = 353 \text{ SF collector needed}$$

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